NATIONAL ADVISORY COMMITTEE
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TECHNICAL NOTE 3854

COMPRESSIVE STRESS-STRAIN PROPERTIES OF 7075-T6

ALUMINUM-ALLOY SHEET AT ELEVATED TEMPERATURES

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SUMMARY

Compressive stress-strain test results for 7075-T6 aluminum-alloy
sheet are presented for temperatures ranging from room temperature to
700° F and for exposure times from 0.1 to 100 hours. All specimens
were loaded parallel to the rolling direction of the sheet and were
tested at a nominal strain rate of 0.002 per minute. Stress-strain
curves are presented for each temperature and exposure time investi-
gated, and significant design data obtained from the curves (compres-
sive yield stress, Young's modulus, secant and tangent moduli, and two
stresses useful for determining the maximum compressive strength of
plates) are presented in graphical and tabular form. A time-temperature
parameter derived from rate-process theory is used to present the com-
pressive yield stresses as a single master curve.

INTRODUCTION

Many studies have been made to determine the effects of elevated
temperature and exposure time on the compressive stress-strain proper-
ties of aluminum-alloy sheet. (See, for example, refs. 1 and 2.)
Although these experimental studies covered a wide range of tempera-
tures and exposure times, no data were obtained which indicate the
effects of short exposure times (less than 1/2 hour) on the elevated-
temperature compressive properties of these alloys. In addition, for
longer exposure times, compressive stress-strain properties were
obtained only for temperature increments of about 100° F. The present
study was made to determine the effects of short exposure time on the
compressive stress-strain properties of aluminum-alloy sheet and also
to obtain conventional compressive stress-strain curves for longer
exposure time (up to 100 hours) at small temperature increments.

In the present investigation compressive stress-strain curves were
obtained from 7075-T6 aluminum-alloy sheet for exposure times from 0.1

to 100 hours and for temperatures from room temperature to 700° F. A similar study was made on 2024-T3 aluminum-alloy sheet. (See ref. 3.) The stress-strain curves are presented for each temperature and exposure time investigated and significant design data obtained from the curves are given in graphical and tabular form. A study was made to determine whether the compressive yield stresses for various combinations of temperature and exposure time can be plotted as a single curve against a time-temperature parameter derived from rate-process theory.

<center>SYMBOLS</center>

ϵ strain

σ stress, psi

σ_{cy} 0.2-percent-offset compressive yield stress, psi

σ_2 stress at which $E_t = \frac{1}{2} E_s$, psi

σ_3 stress at which $E_t = \frac{1}{3} E_s$, psi

E   Young's modulus, psi

E_s secant modulus, psi

E_t tangent modulus, psi

t   exposure time, hr

T   temperature, °F

T_R temperature, °R

<center>TEST SPECIMENS AND PROCEDURES</center>

The compressive stress-strain specimens were 1.00 inch wide and 2.52 inches long. All specimens were machined from one sheet of 7075-T6 aluminum alloy of 0.064-inch nominal thickness with the longitudinal axes of the specimens parallel with the rolling direction of the sheet. The specimens were tested in the compressive stress-strain test equipment

shown in figure 1 and described in reference 4. Temperature variation over the 1-inch gage length of the specimens did not exceed 5° F during the tests, and specimen temperatures during the tests were maintained within ±5° F of the test temperature. The rate of loading was controlled to achieve as closely as possible a strain rate of 0.002 per minute for all specimens.

For exposure times of 1 hour or less the specimens were inserted in the preheated compressive stress-strain test fixtures and were maintained at test temperature for the desired time prior to loading. Exposure time for these specimens is defined as the time at test temperature prior to loading plus the time required to load the specimens to the compressive yield stress. For exposure times greater than 1 hour, the specimens were heated in an oven at the desired test temperatures for the designated exposure times. These specimens were then cooled to room temperature and subsequently reheated to the test temperatures in the compression stress-strain equipment prior to loading. Testing of these specimens began immediately after the desired test temperature was achieved.

Three specimens were tested at each temperature for a 0.5-hour exposure. Only one specimen was tested at each of the other temperatures and exposure times.

RESULTS AND DISCUSSION

Test Results

Compressive stress-strain curves obtained from the tests for temperatures up to 700° F and for a 0.5-hour exposure at the elevated temperatures are given in figure 2. The curves are typical results obtained from tests of three specimens at each temperature. The 0.2-percent-offset compressive yield stresses are indicated by the tick marks. Figures 3 to 14 present compressive stress-strain curves obtained for temperatures from 200° F to 700° F and for exposure times from 0.1 to 100 hours. A summary of the compressive properties obtained from the stress-strain curves shown in figures 2 to 14 is given in table I.

A curve of average values of Young's modulus obtained from the tests at each temperature is given in figure 15. The scatter in the experimental values of Young's modulus ranged from approximately ±2 percent at the low test temperatures to ±6 percent at the high test temperatures. No significant change in Young's modulus was obtained at a given temperature for different exposure times. Results of studies by previous investigators have indicated that no significant change in Young's modulus should be expected for different exposure times at a given temperature. (For example, see ref. 2.)

The effect of exposure time at the different test temperatures on the compressive yield stress is shown in figure 16. Experimental results are shown by the symbols. Solid lines are drawn through the data within the range of exposure times investigated at each temperature. The dashed curves indicate estimated values of compressive yield stress obtained from a cross plot of the data in figure 16 into the form shown in figure 17.

The results shown in figure 16 indicate that the maximum compressive yield stresses at each temperature were obtained for the shortest exposure time. The 7075-T6 aluminum-alloy sheet in the "as received" condition is artificially aged to maximum strength and additional exposure at elevated temperatures produces overaging with a resultant loss of strength. In contrast, the compressive strength of a naturally aged material such as 2024-T3 aluminum alloy can be increased by exposure at elevated temperatures. (For example, see ref. 3.) In the range of exposure times investigated for 7075-T6 aluminum alloy, very small changes in compressive yield stress were obtained with increasing exposure time for temperatures up to 300° F, substantial changes were obtained for temperatures from 350° F to 600° F, and only a slight change was obtained at a temperature of 700° F.

Figure 18 presents the change of secant modulus with stress for temperatures ranging from room temperature to 700° F for a 0.5-hour exposure at the elevated temperatures. Figures 19 to 30 show the change of secant modulus with stress at each test temperature for different exposure times. The change of tangent modulus with stress at the elevated temperature is given in figure 31 for the 0.5-hour exposure and in figures 32 to 43 for all exposure times investigated at the elevated temperatures. The secant and tangent moduli presented here were determined from stress-strain curves obtained for a given strain rate. Considerably different values of tangent moduli may be expected for other strain rates; however, the values of secant modulus are not expected to change appreciably.

Figures 44 and 45 present the changes of σ_2 and σ_3, respectively, with exposure time for the different test temperatures. The stresses σ_2 and σ_3 are defined in reference 5 as the stresses at which $E_t = \frac{1}{2} E_s$ and $E_t = \frac{1}{3} E_s$, respectively. These stresses were shown to be useful in the determination of maximum compressive strength of plates (ref. 5) and may also be considered to be suitable definitions of compressive strength for materials at elevated temperatures. Values of both σ_2 and σ_3 show changes with exposure time at the different temperatures that approximate the changes in the compressive yield stress. The compressive yield stress, however, is greater than either σ_2 or σ_3 at any corresponding temperature and exposure time. The values of σ_2 and σ_3 determined from each stress-strain curve are listed in table I.

Master Compressive-Yield-Stress Curve

A time-temperature parameter used previously for correlating the hardness of steels with time and tempering temperatures (ref. 6) was investigated to determine whether the yield stresses shown in figure 16 could be presented as a single master curve. The time-temperature parameter is $T_R(24 + \log_{10} t)$, where T_R is temperature in degrees Rankine, 24 is a material constant (determined from equation [A8] of ref. 6), and t is exposure time in hours. Compressive yield stresses obtained in the present investigation are plotted as a function of this time-temperature parameter in figure 46. Test results are shown for temperatures from 300° F to 700° F and for exposure times from 0.1 to 100 hours. Compressive yield stresses determined for temperatures below 300° F are omitted from this figure. For these relatively low temperatures no significant changes in yield stresses were obtained in the range of exposure times investigated. In the temperature range from 300° F to 400° F relatively small changes in compressive yield stress were obtained for some of the short exposure times. These data do not lie on the master curve and have been connected by dashed lines for each temperature. The master curve of figure 46 appears useful for estimating compressive yield stresses at different temperatures and exposure times except at the low temperatures. No data are available to indicate whether the master curve can be used successfully to predict compressive yield stresses outside of the range investigated, particularly for very short exposure times at high temperatures.

CONCLUDING REMARKS

The results of compressive stress-strain tests of 7075-T6 aluminum-alloy sheet indicate that the compressive yield stress decreases with increasing temperature and that the highest value of compressive yield stress is obtained for the shortest exposure time at each temperature. For exposure times from 0.1 to 100 hours the changes in compressive yield stress with exposure time were not significant up to 300° F and at 700° F; for temperatures between 350° F and 600° F substantial changes were obtained. No significant change in Young's modulus was obtained for different exposure times at any given temperature. A time-temperature parameter was used to obtain a master yield-stress curve for all compressive yield stresses except those at the lower temperatures where small changes in yield stress were obtained for different exposure times.

Langley Aeronautical Laboratory,
    National Advisory Committee for Aeronautics,
        Langley Field, Va., August 6, 1956.

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TABLE I.- COMPRESSIVE PROPERTIES OF 7075-T6 ALUMINUM-ALLOY SHEET

FOR VARIOUS TEMPERATURES AND EXPOSURE TIMES

[Nominal sheet thickness, 0.064 inch; nominal
strain rate, 0.002 per minute]

T, $°F$	Exposure, hr	σ_{cy}, psi	E, psi	σ_2, psi	σ_3, psi
Room	-----	$.71.7 \times 10^3$	10.5×10^6	64.5×10^3	69.0×10^3
200	0.1	66.9	10.0	60.5	64.4
200	.5	66.9	10.2	60.5	64.4
200	1	66.8	10.0	60.5	64.4
250	.1	63.5	9.9	57.0	60.8
250	.5	62.2	9.7	56.2	60.0
250	1	62.5	9.7	56.2	60.0
300	.1	57.7	9.4	52.2	55.0
300	.5	56.6	9.6	50.9	54.5
300	1	56.0	9.7	50.8	53.4
300	4	56.2	9.5	51.0	53.6
300	10	55.0	9.3	49.5	52.6
300	40	53.4	9.3	48.0	50.5
300	100	49.5	9.7	44.5	46.5
350	.1	50.6	8.9	45.5	48.0
350	.5	50.5	9.0	45.2	48.0
350	1	49.2	9.3	44.3	46.9
350	4	46.2	9.0	41.4	43.5
350	10	40.2	9.2	36.0	37.8
350	40	34.1	8.9	30.3	31.8
350	100	27.3	9.2	24.0	27.6
375	.1	48.0	8.9	42.8	45.5
375	.2	46.9	8.9	42.5	45.0
375	.3	45.6	8.7	41.1	44.0
375	.4	45.2	8.7	40.5	43.5
375	.5	44.4	8.8	39.4	42.8
375	1	40.4	8.7	36.0	38.8
400	.1	42.5	8.7	38.5	41.1
400	.2	42.5	8.5	38.3	40.9
400	.3	39.8	8.5	35.5	38.1
400	.4	39.2	8.6	35.4	38.0
400	.5	38.9	8.6	34.5	36.5
400	1	35.9	8.7	32.0	34.0
400	4	29.2	8.6	25.4	27.0
400	10	23.6	8.5	20.2	21.4
400	40	20.3	8.7	18.3	19.0
400	100	18.8	8.7	16.3	17.5
425	.1	38.0	8.6	34.0	35.9
425	.2	35.5	8.4	31.2	33.8
425	.3	32.1	8.3	28.3	30.5
425	.4	31.7	8.5	27.5	29.8
425	.5	30.3	8.3	26.3	28.2
425	1	26.1	8.0	22.9	24.5

TABLE I.- COMPRESSIVE PROPERTIES OF 7075-T6 ALUMINUM-ALLOY SHEET

FOR VARIOUS TEMPERATURES AND EXPOSURE TIMES - Concluded

[Nominal sheet thickness, 0.064 inch; nominal
strain rate, 0.002 per minute]

T, °F	Exposure, hr	σ_{cy}, psi	E, psi	σ_2, psi	σ_3, psi
450	.1	31.1×10^3	8.0×10^6	27.7×10^3	29.9×10^3
450	.2	29.0	7.8	25.5	27.3
450	.3	26.7	8.2	23.8	25.2
450	.4	26.0	8.2	22.0	24.7
450	.5	23.9	8.0	20.5	22.3
450	1	21.9	8.3	18.5	20.4
450	4	18.6	7.8	15.8	16.9
450	10	16.0	7.9	13.5	14.5
450	40	14.4	8.1	12.0	12.8
450	100	13.6	8.3	11.5	12.2
500	.1	21.0	7.6	17.2	19.4
500	.2	19.4	7.8	16.5	18.0
500	.3	18.8	7.2	15.6	17.2
500	.4	18.3	7.2	14.8	16.3
500	.5	17.0	7.6	14.0	15.6
500	1	15.8	7.5	13.0	14.5
500	4	13.0	7.3	10.6	11.7
500	10	11.6	7.5	9.7	10.5
500	40	10.0	7.2	8.4	9.0
500	100	8.5	7.7	6.8	7.5
550	.1	15.1	7.0	13.5	14.5
550	.2	13.8	6.9	11.0	12.5
550	.3	13.6	7.0	10.9	12.2
550	.4	12.3	6.6	9.4	10.8
550	.5	11.3	6.9	8.8	9.9
550	1	10.6	6.6	8.1	9.4
600	.1	10.4	6.1	8.2	9.1
600	.2	9.1	6.4	6.8	7.9
600	.3	8.4	5.9	6.3	7.3
600	.4	8.2	5.9	6.0	7.0
600	.5	7.9	6.2	5.7	6.8
600	1	7.6	6.0	5.5	6.5
700	.1	5.6	4.7	4.3	4.8
700	.2	5.5	4.2	4.2	4.7
700	.3	5.3	4.5	4.0	4.5
700	.4	5.2	4.2	3.6	4.3
700	.5	5.3	4.6	3.6	4.2
700	1	4.9	4.3	3.4	4.1
700	4	4.7	4.5	3.3	4.1
700	10	4.7	4.6	3.2	4.0
700	40	4.6	4.7	3.2	4.0
700	100	4.4	4.3	3.2	4.0
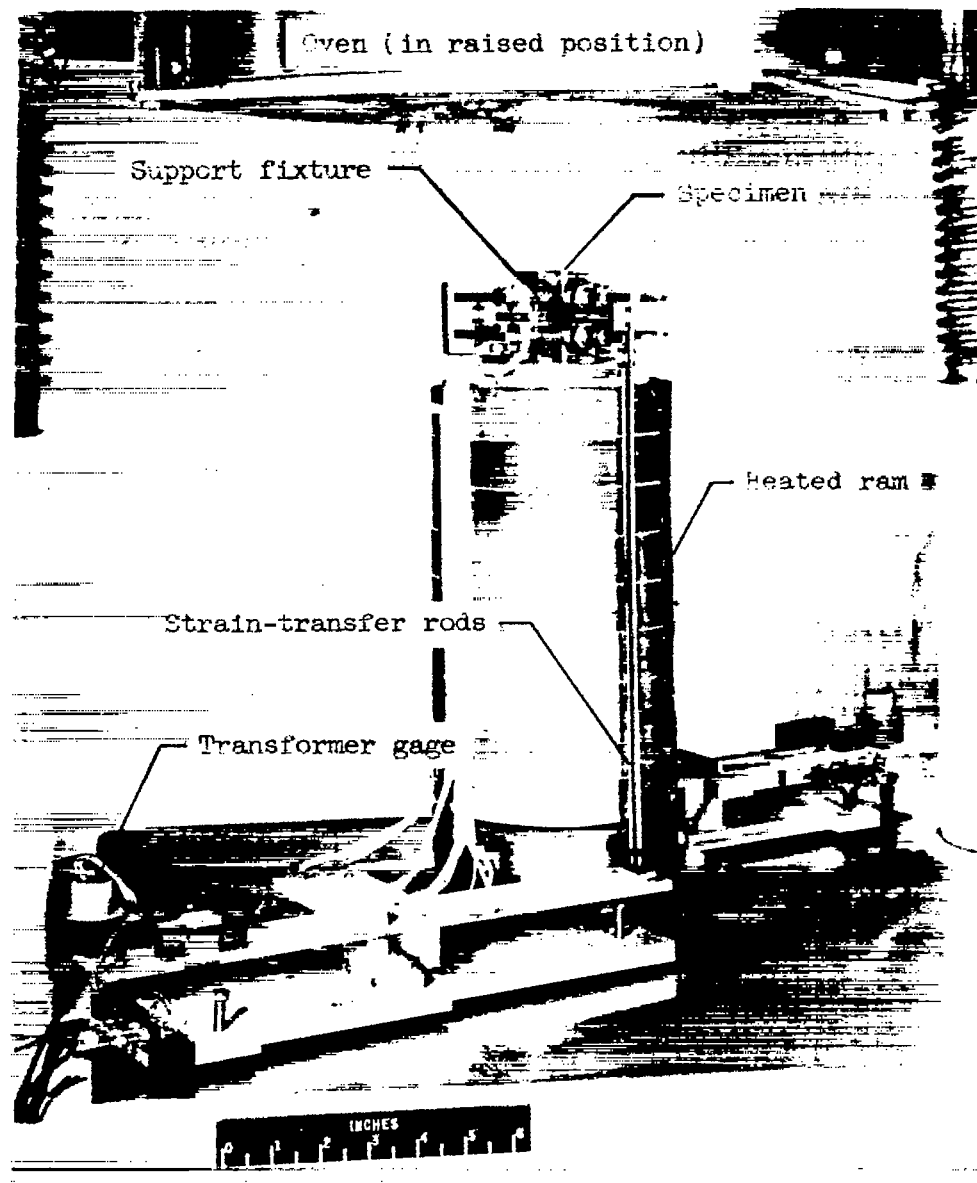
Figure 1.- Equipment for compressive stress-strain tests.

L-85457.1
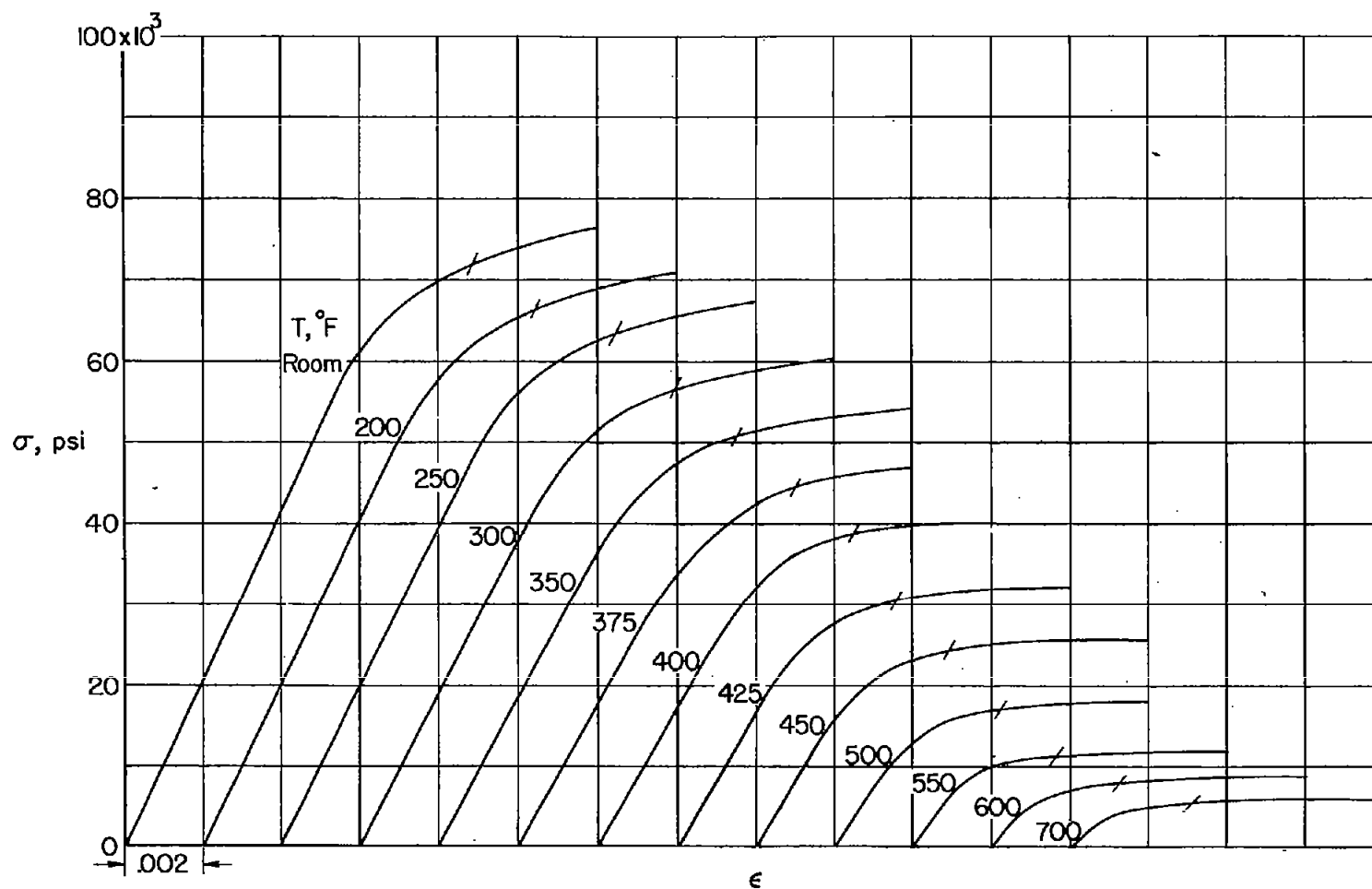
Figure 2.- Compressive stress-strain curves for 7075-T6 aluminum-alloy sheet. 0.5-hour exposure; strain rate, 0.002 per minute.
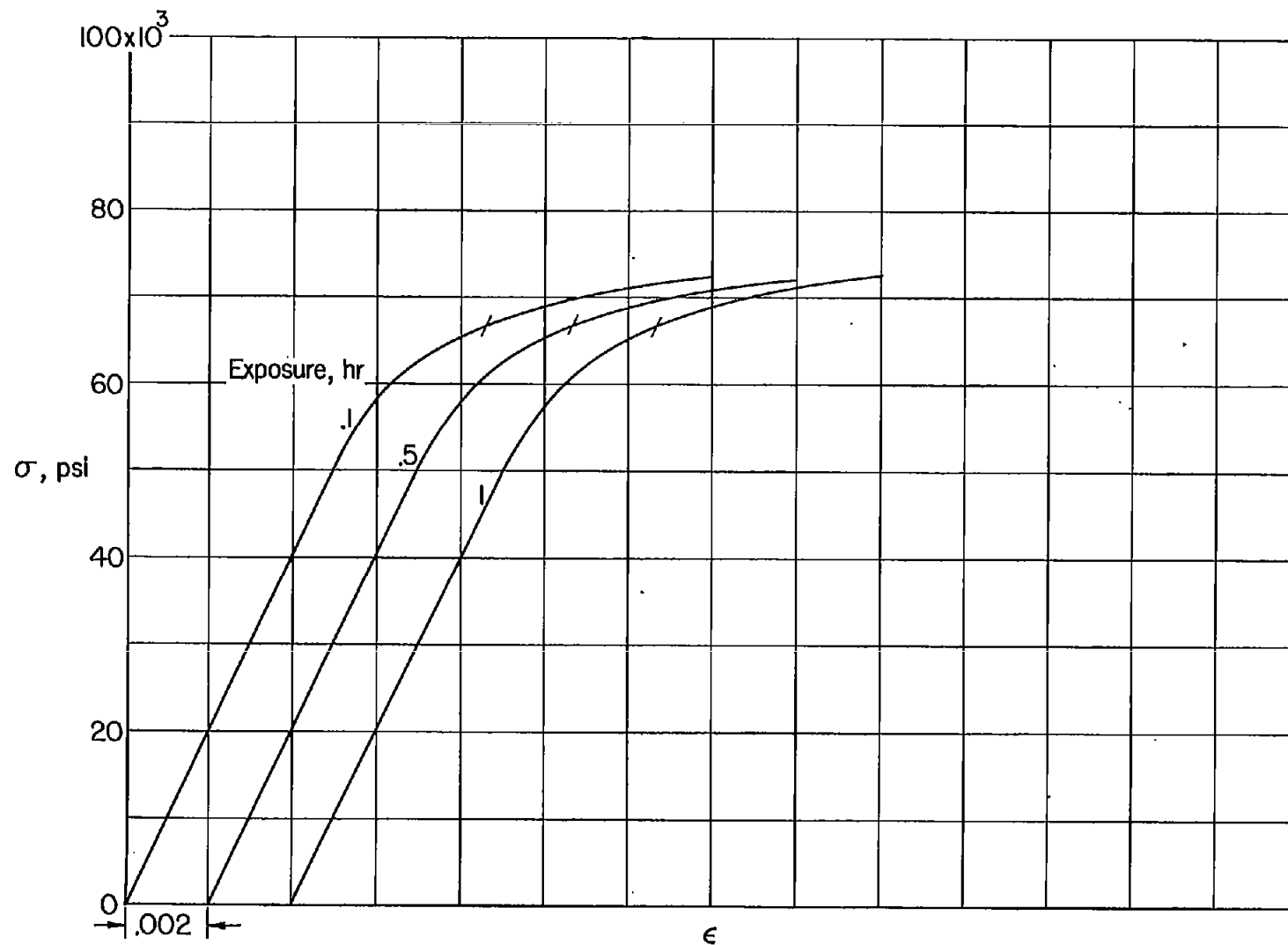
Figure 3.- Compressive stress-strain curves for 7075-T6 aluminum-alloy
sheet at 200° F.
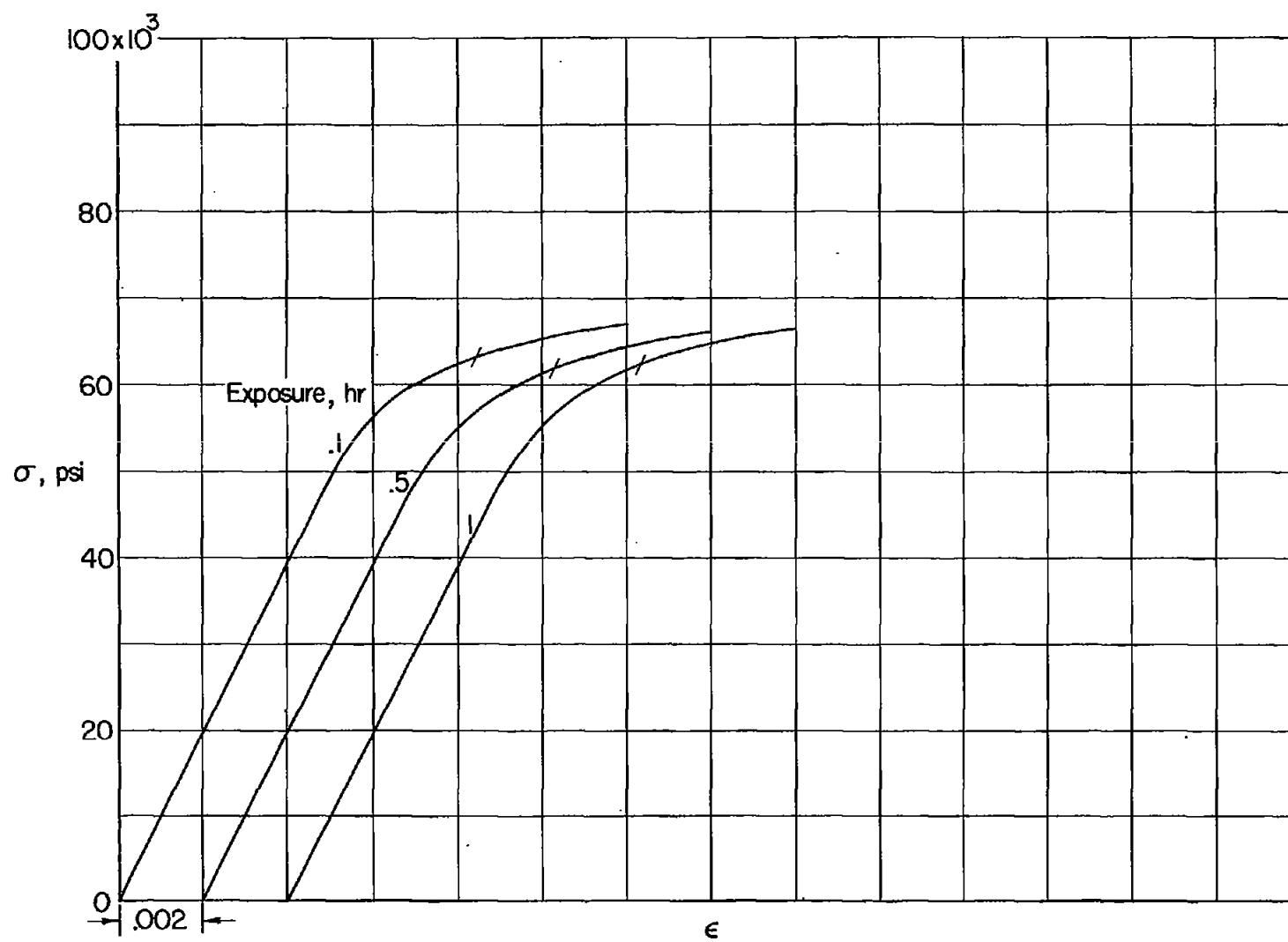
Figure 4.- Compressive stress-strain curves for 7075-T6 aluminum-alloy sheet at 250° F.
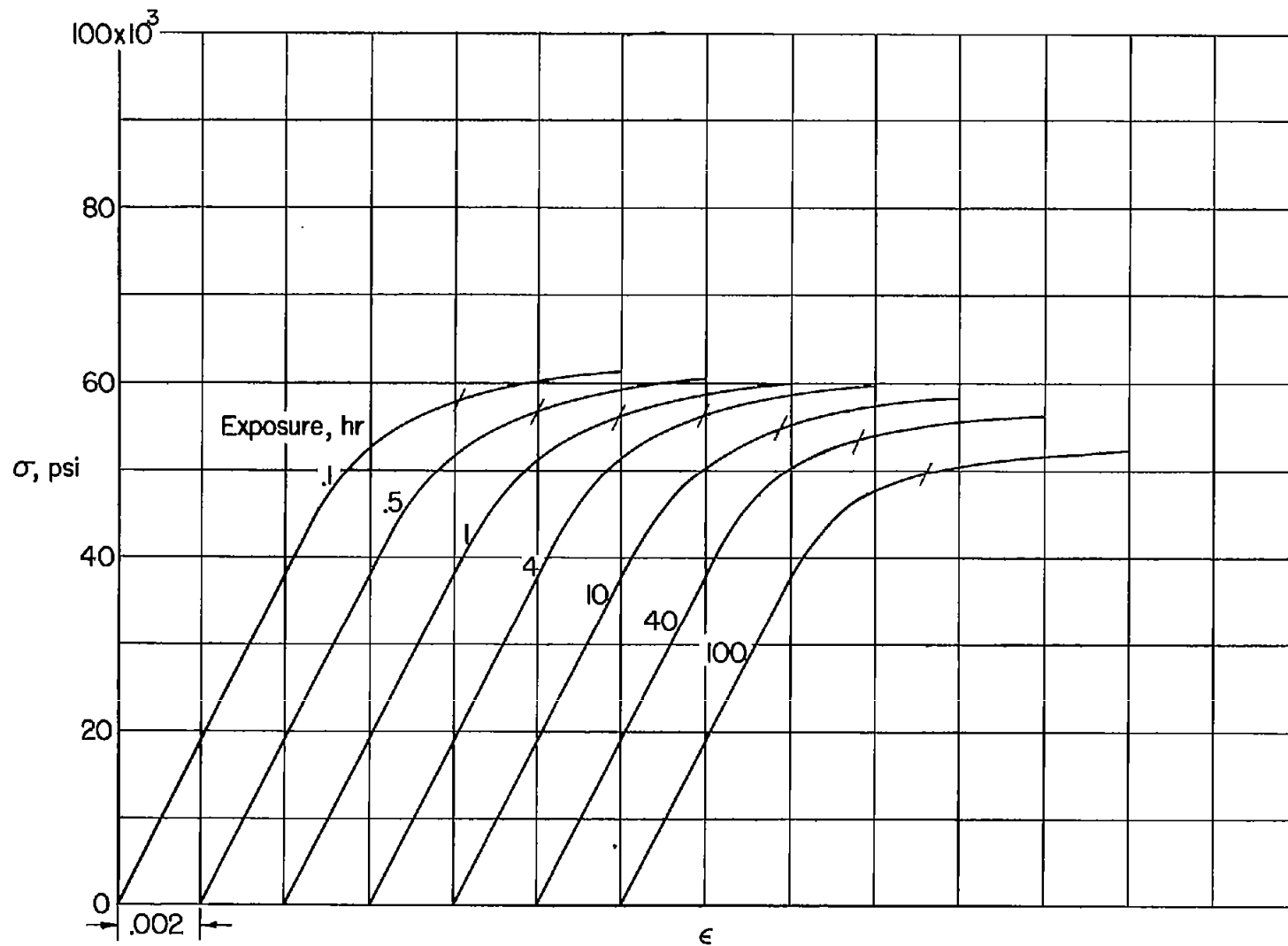
Figure 5.- Compressive stress-strain curves for 7075-T6 aluminum-alloy sheet at 300° F.
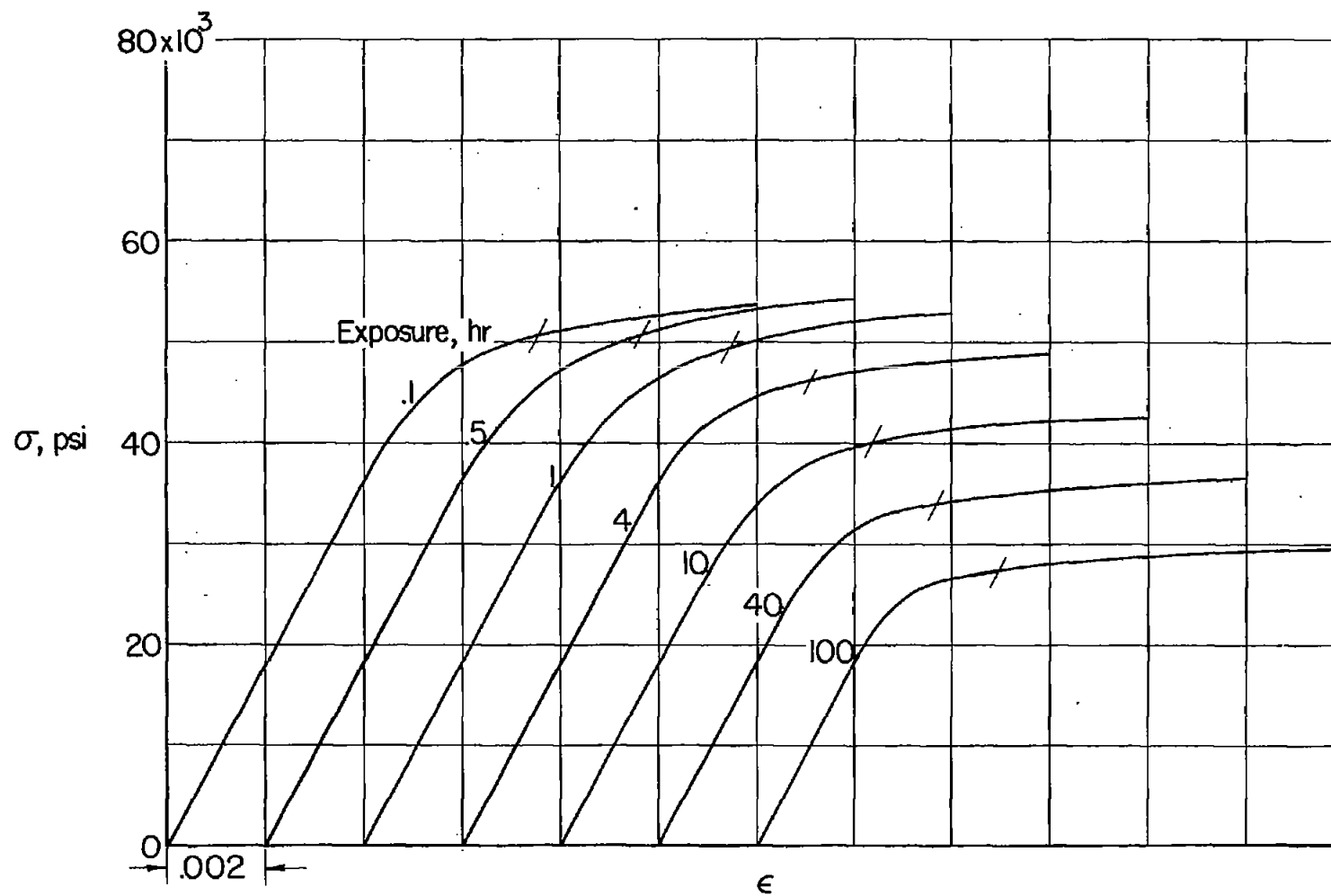
Figure 6.- Compressive stress-strain curves for 7075-T6 aluminum-alloy sheet at 350° F.
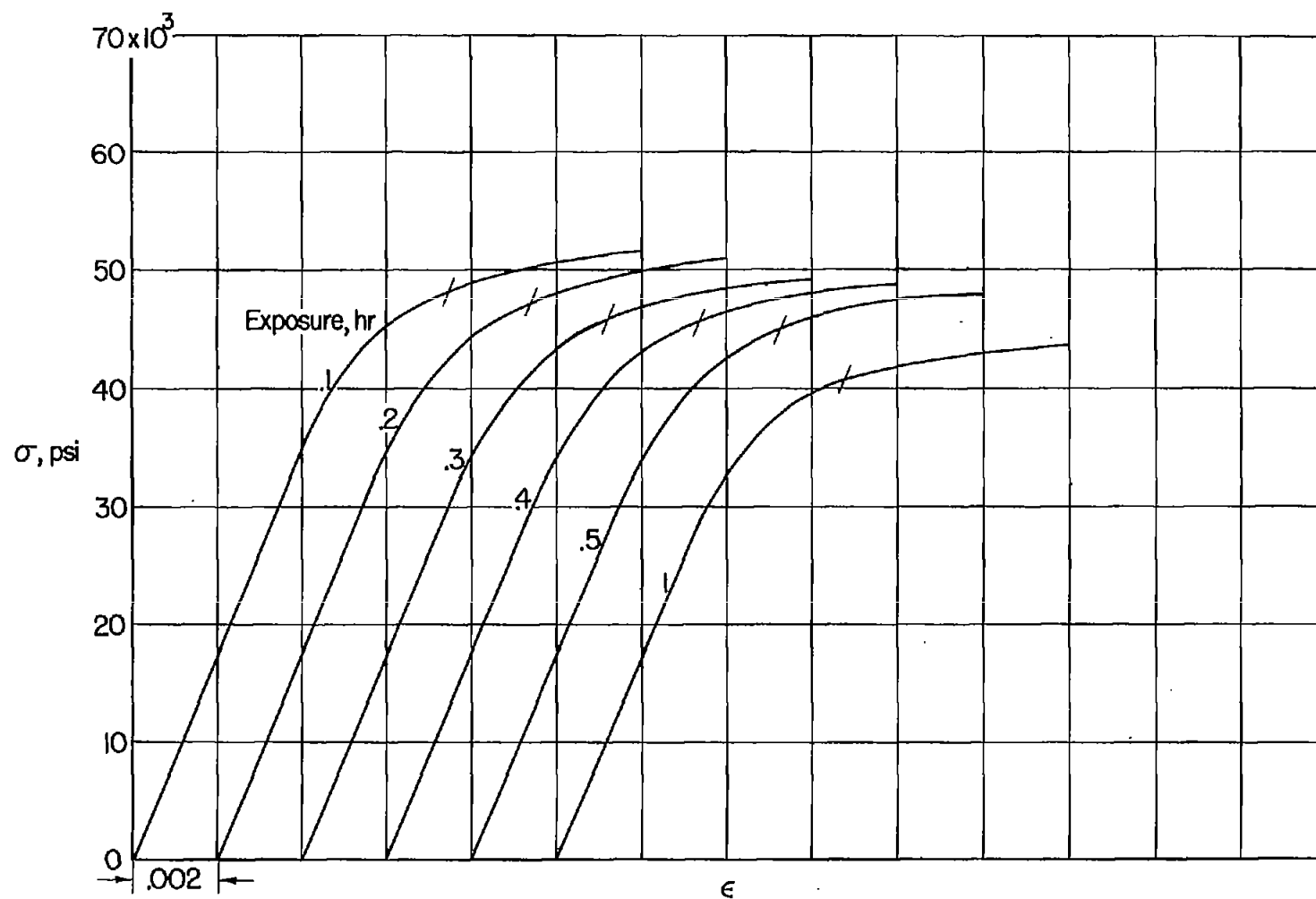
Figure 7.- Compressive stress-strain curves for 7075-T6 aluminum-alloy
sheet at 375° F.
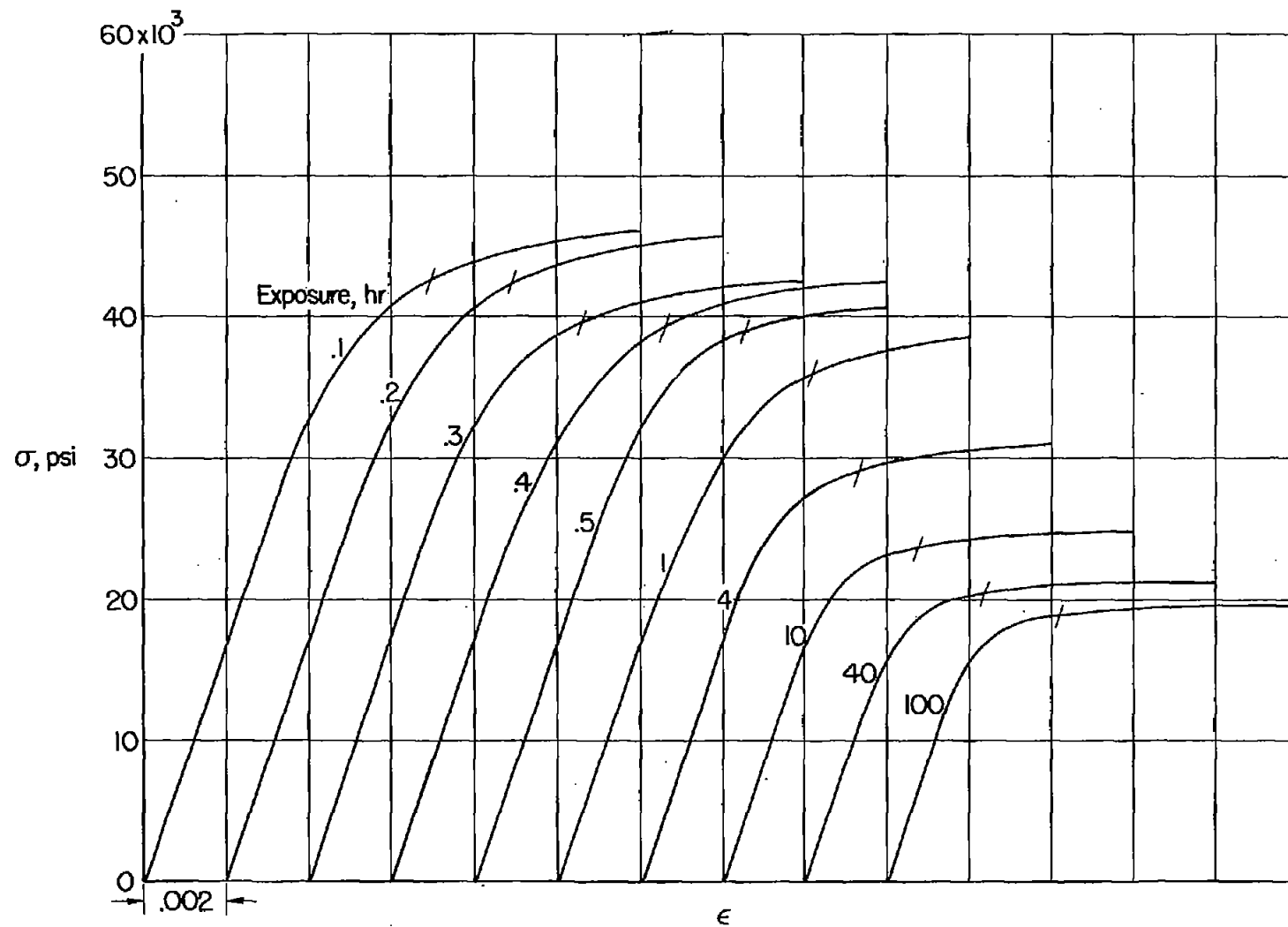
Figure 8.- Compressive stress-strain curves for 7075-T6 aluminum-alloy sheet at 400° F.
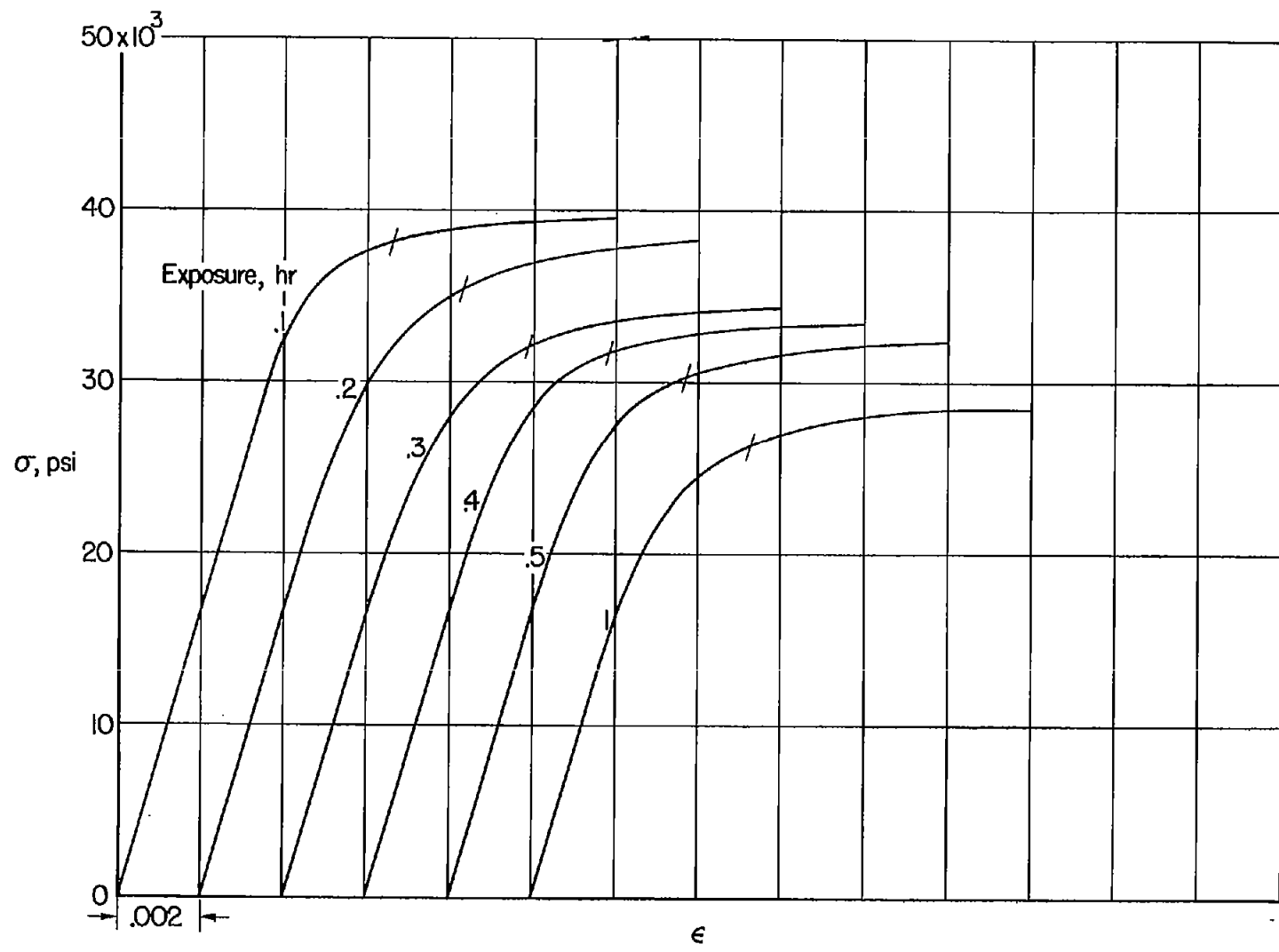
Figure 9.- Compressive stress-strain curves for 7075-T6 aluminum-alloy
sheet at 425° F.
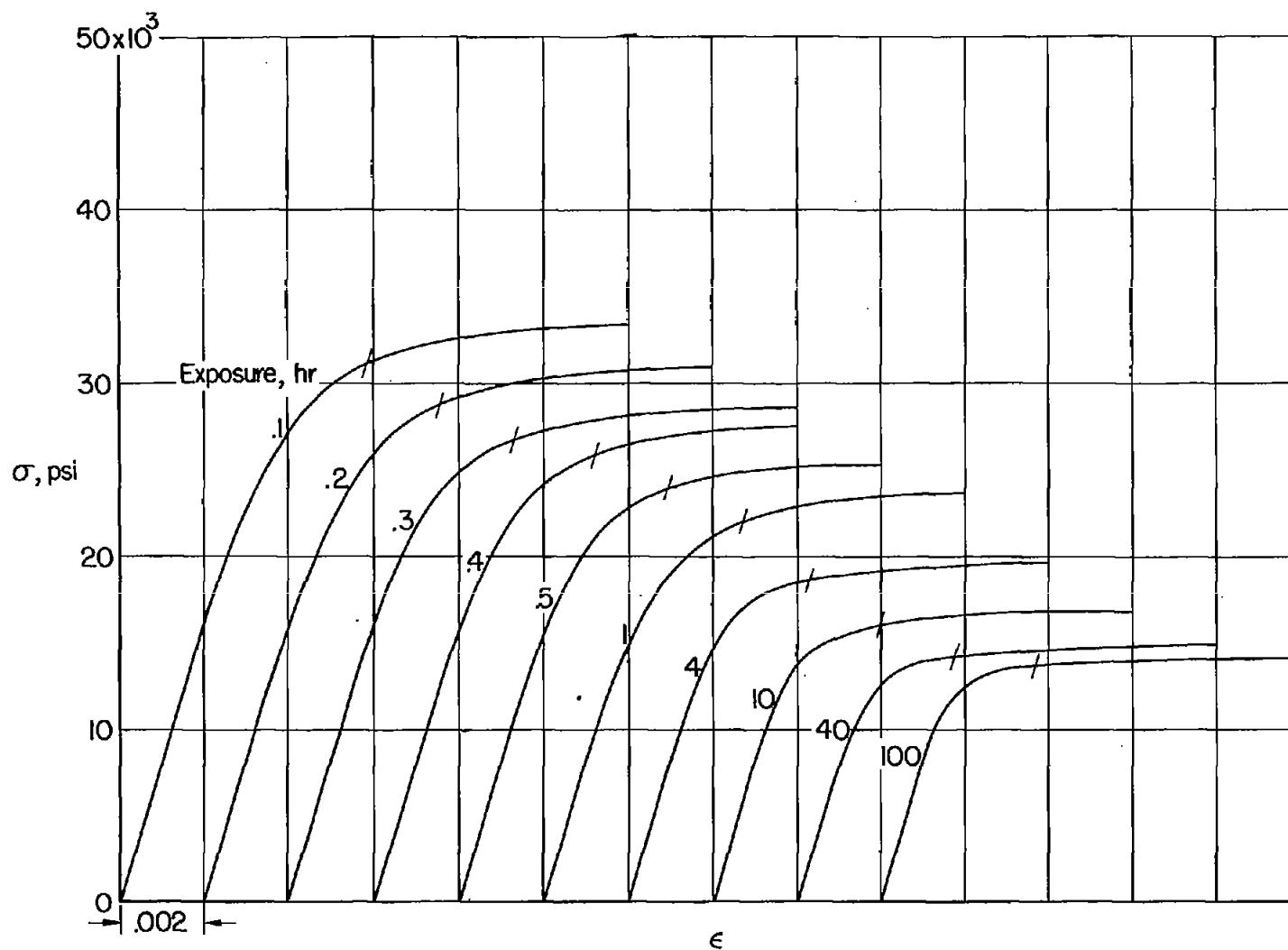
Figure 10.- Compressive stress-strain curves for 7075-T6 aluminum-alloy sheet at 450° F.
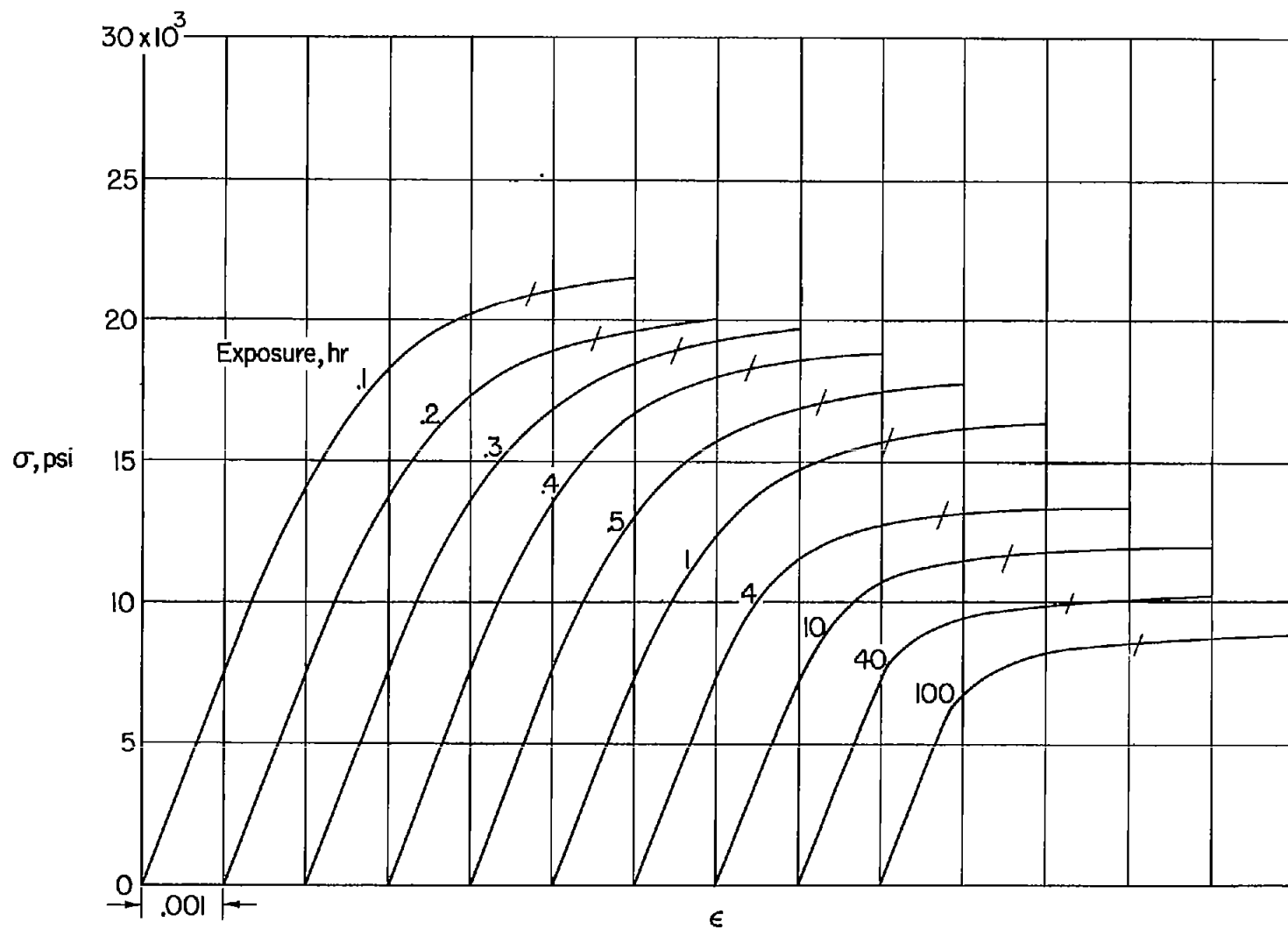
Figure 11.- Compressive stress-strain curves for 7075-T6 aluminum-alloy sheet at 500° F.
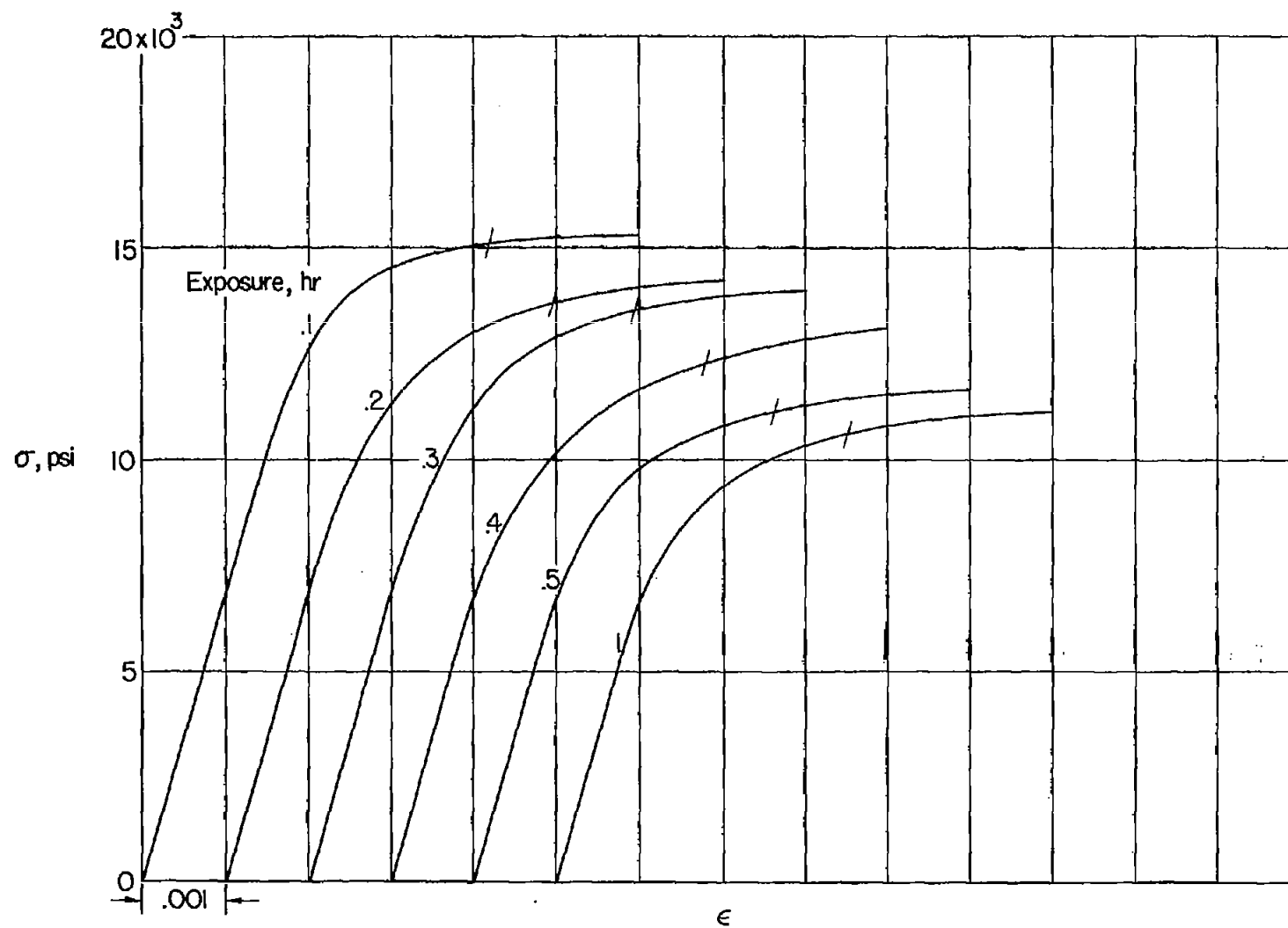
Figure 12.- Compressive stress-strain curves for 7075-T6 aluminum-alloy sheet at 550° F.
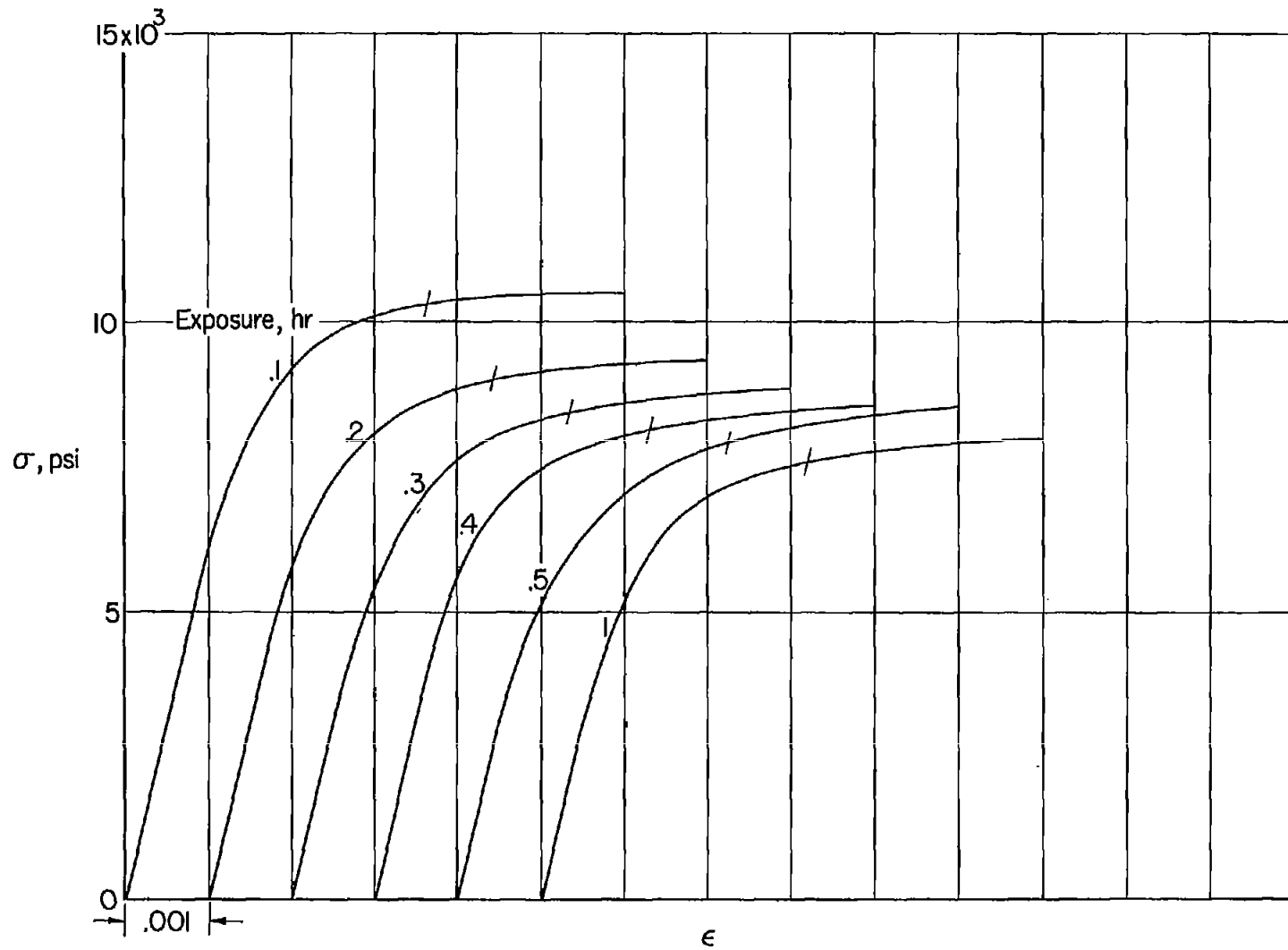
Figure 13.- Compressive stress-strain curves for 7075-T6 aluminum-alloy sheet at 600° F.
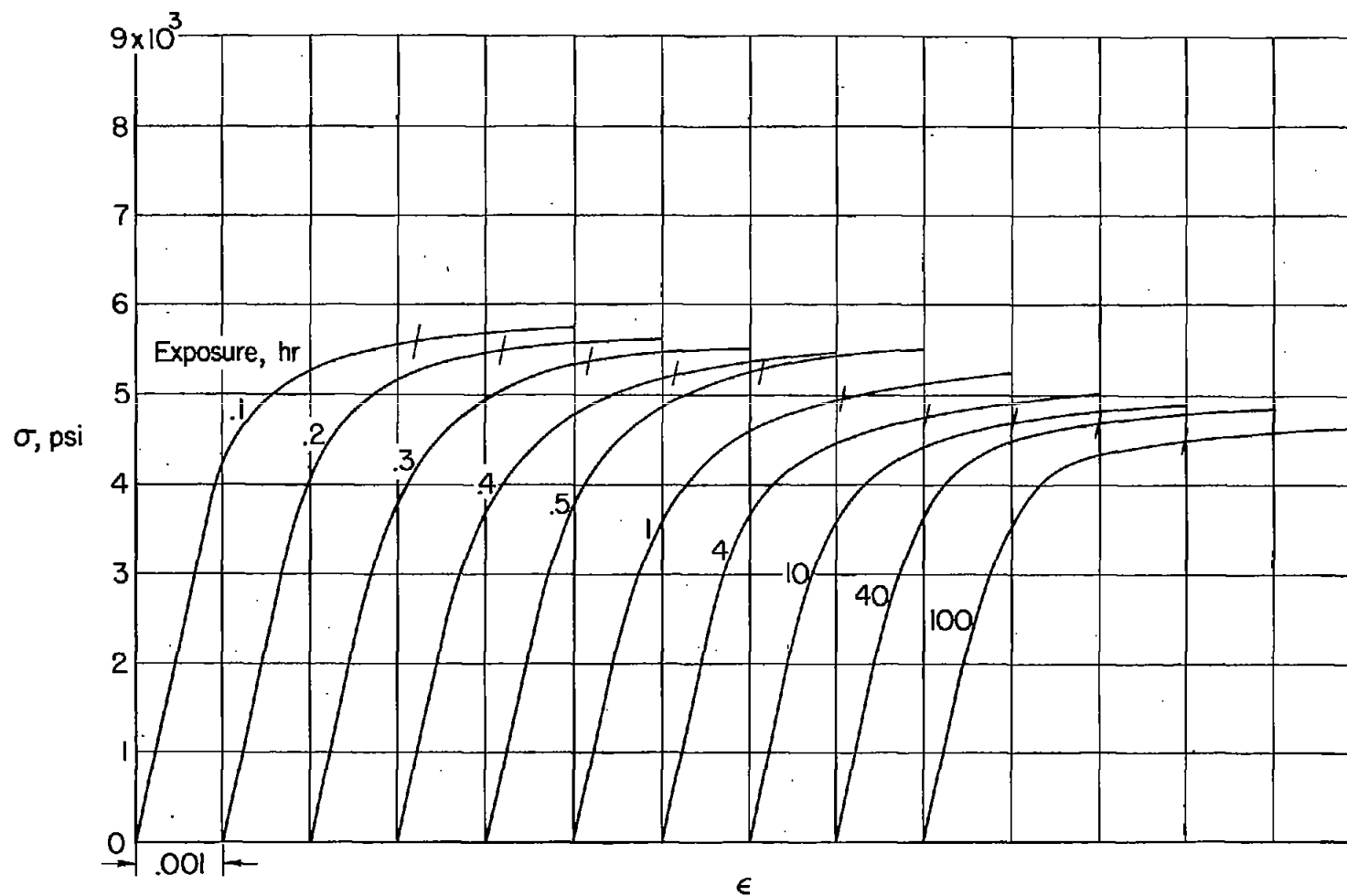
Figure 14.- Compressive stress-strain curves for 7075-T6 aluminum-alloy sheet at 700° F.
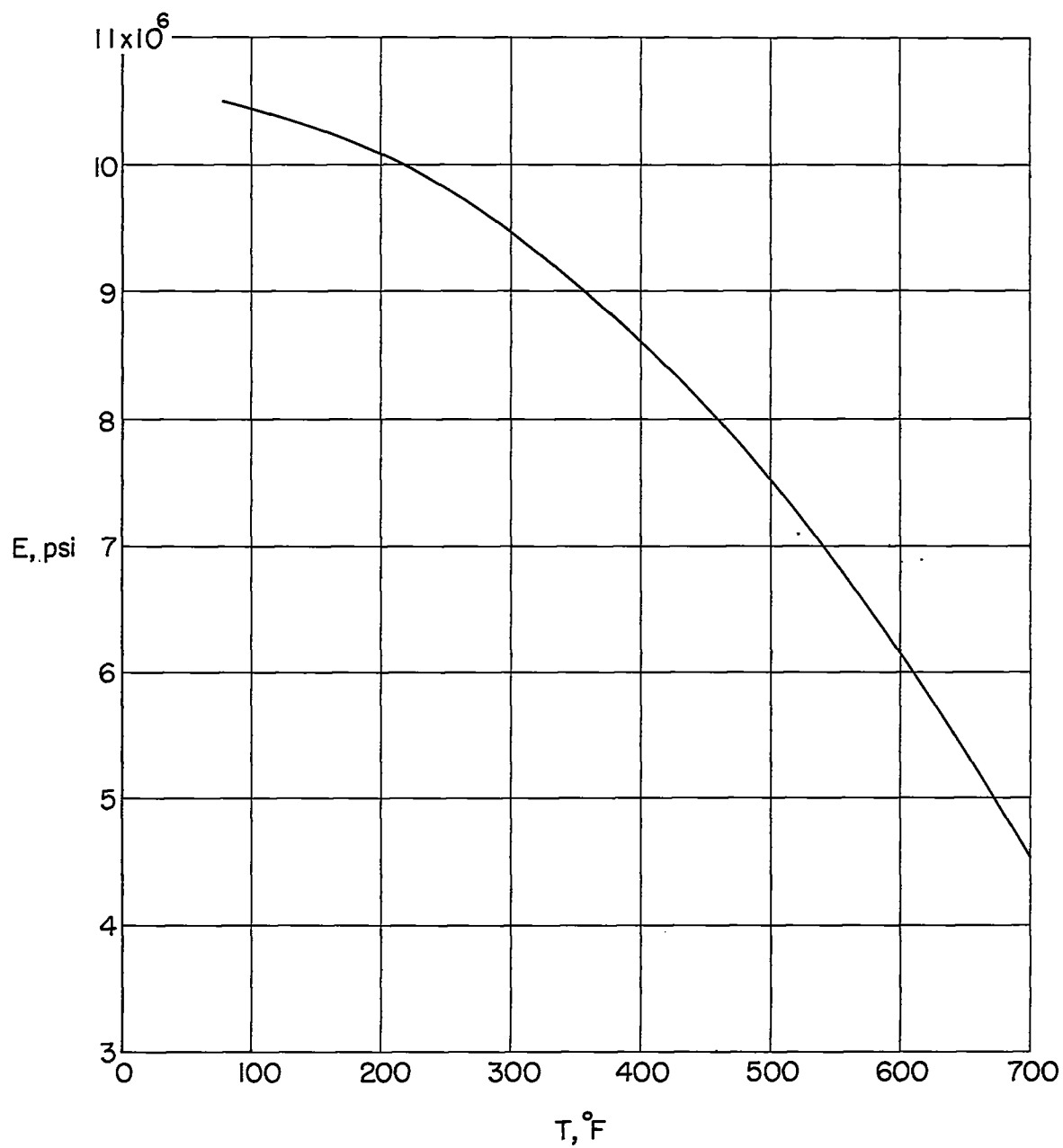
Figure 15.- Effect of temperature on Young's modulus for 7075-T6 aluminum-alloy sheet.
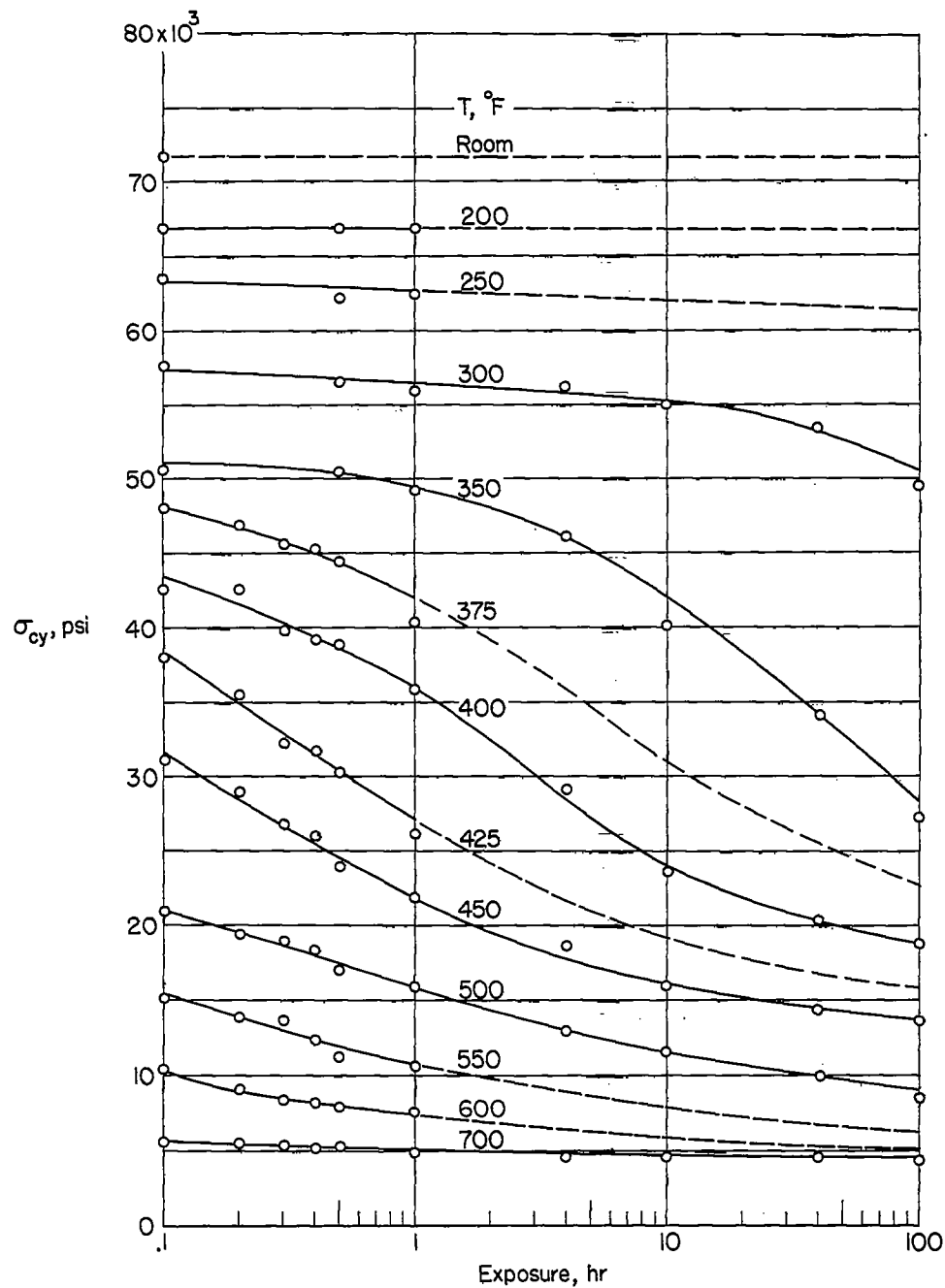
Figure 16.- Effect of temperature and exposure time on the 0.2-percent-offset compressive yield stresses for 7075-T6 aluminum-alloy sheet. (Dashed portions of curves indicate estimated values obtained from fig. 17.)
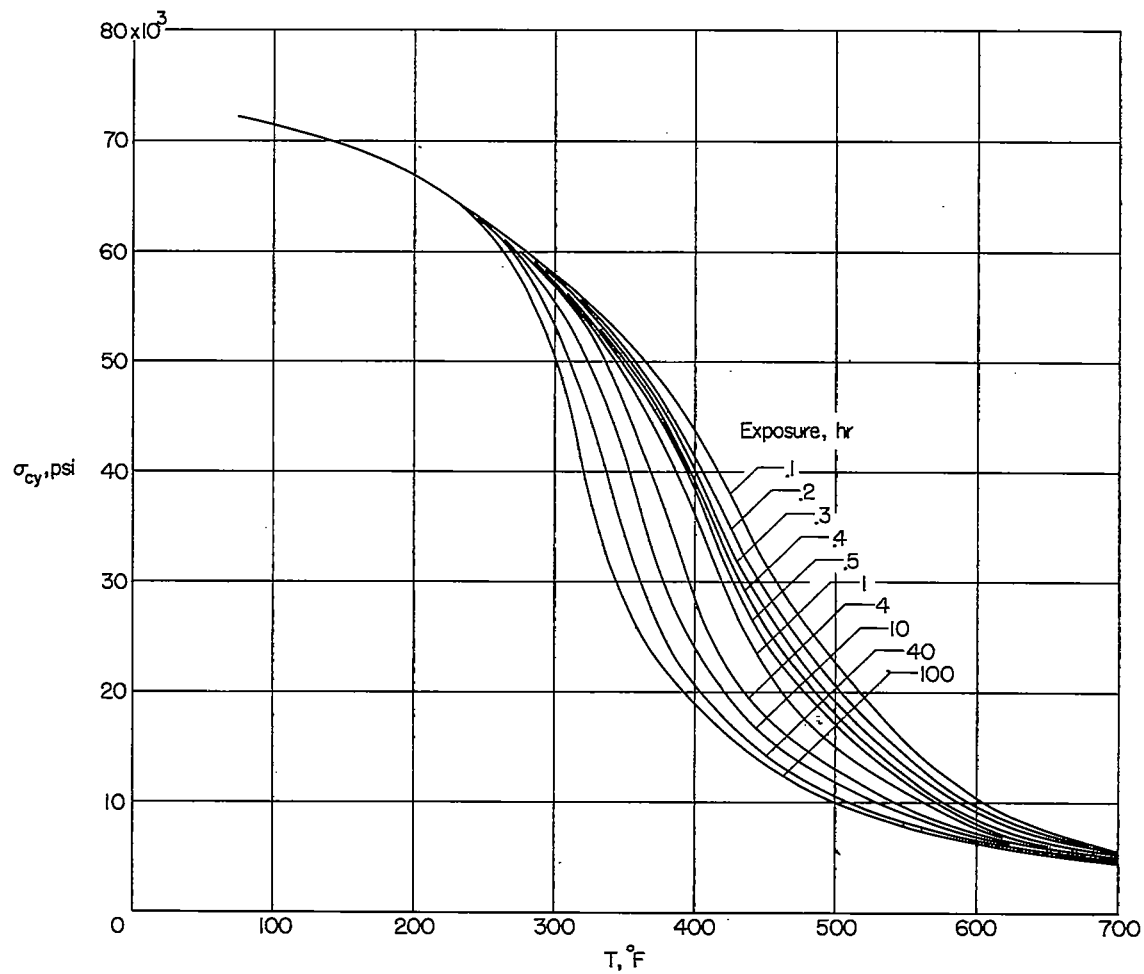
Figure 17.- Effect of temperature and exposure time on the 0.2-percent-
offset compressive yield stresses for 7075-T6 aluminum-alloy sheet
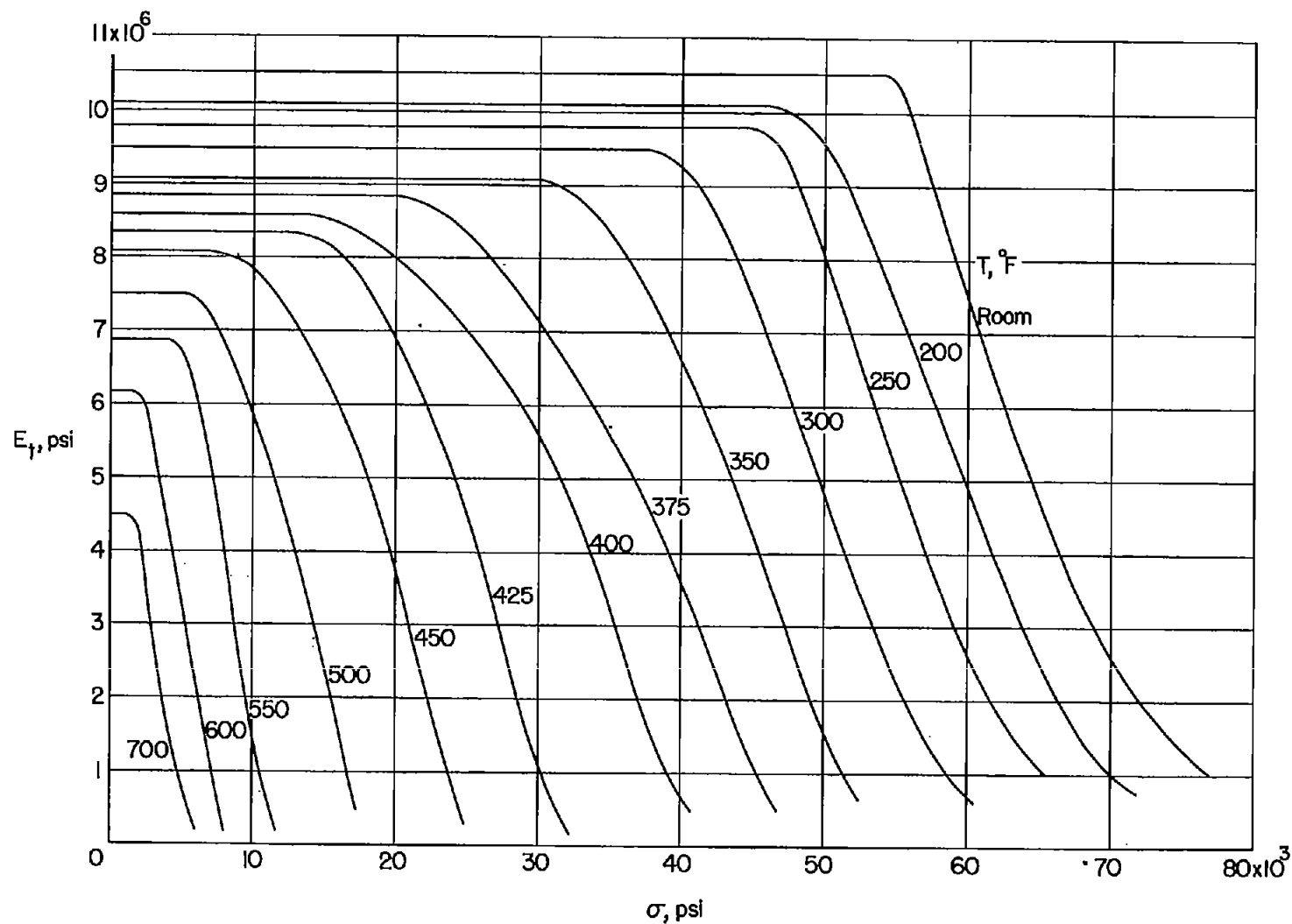(obtained by cross-plotting data in fig. 16).
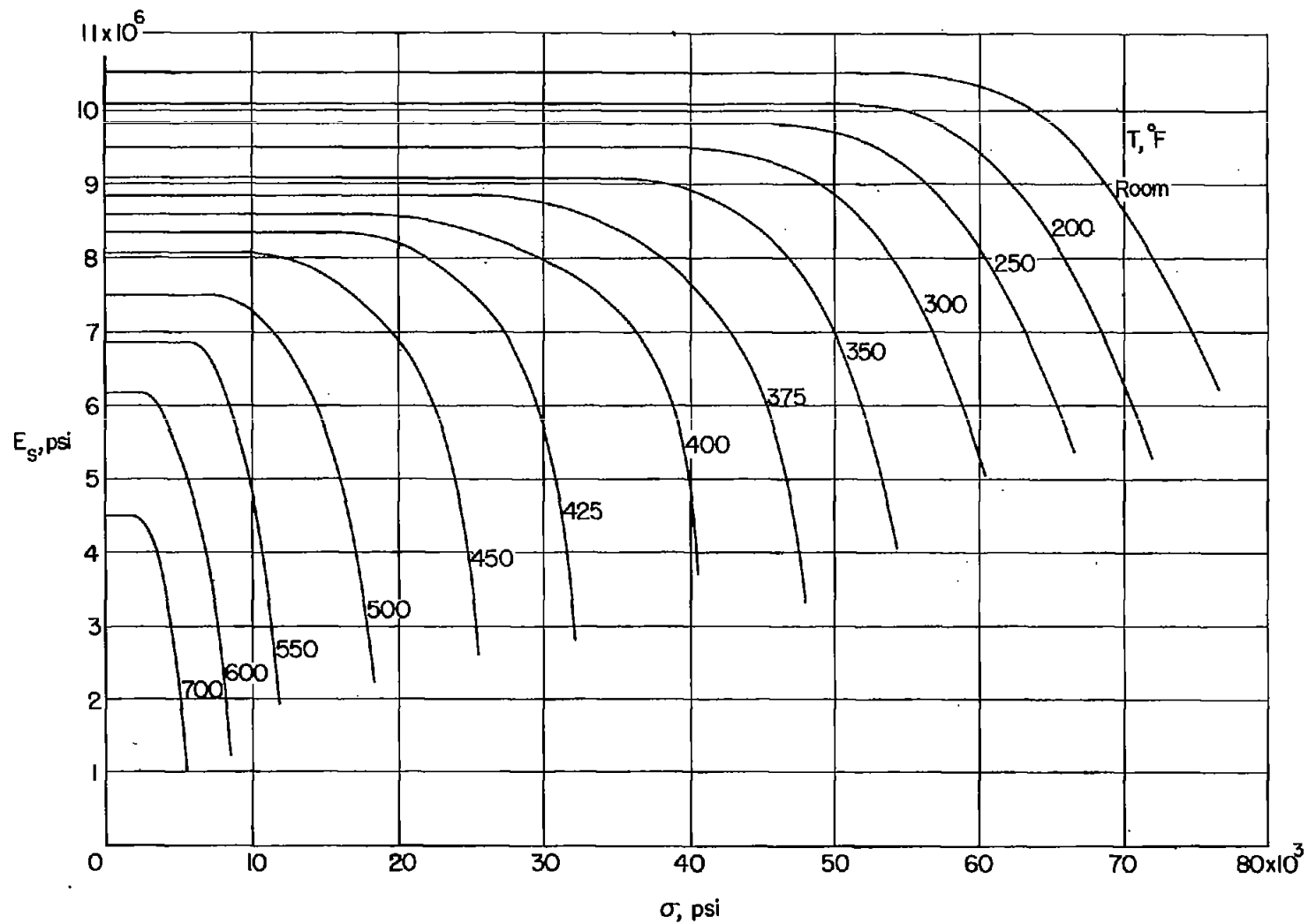
Figure 18.- Variation of secant modulus with stress for 7075-T6 aluminum-
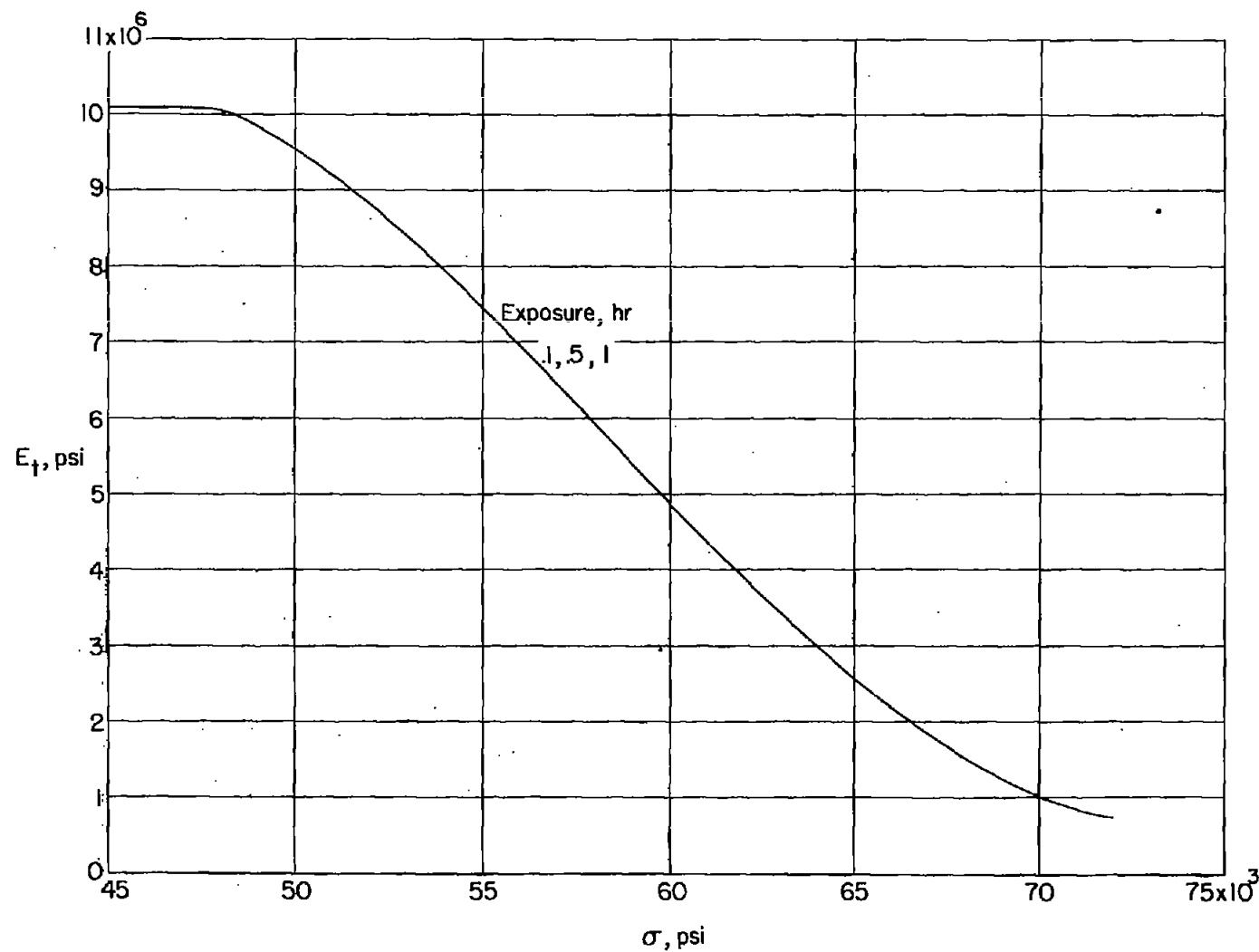alloy sheet. 0.5-hour exposure.
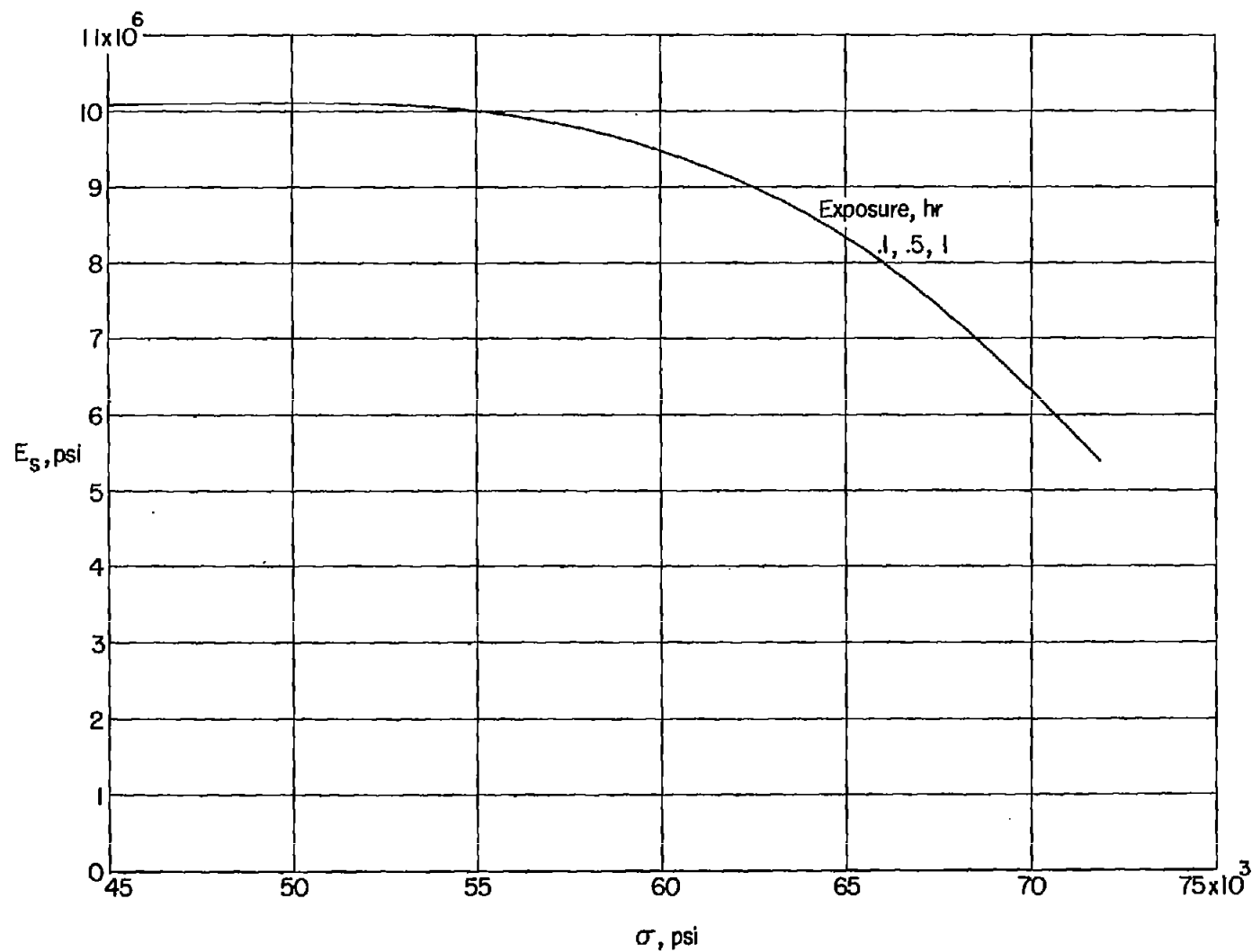
Figure 19.- Variation of secant modulus with stress for 7075-T6 aluminum-alloy sheet at 200° F.
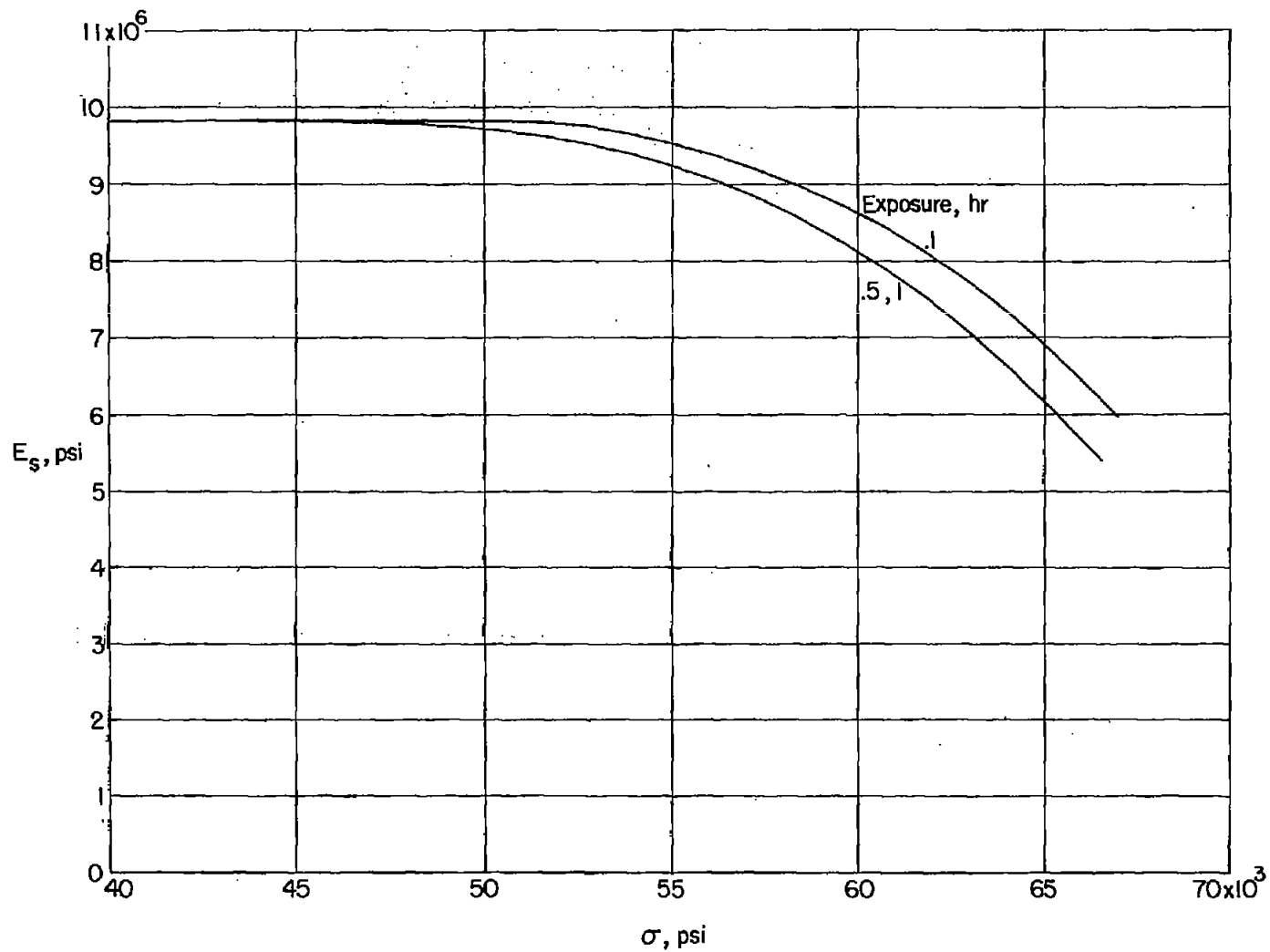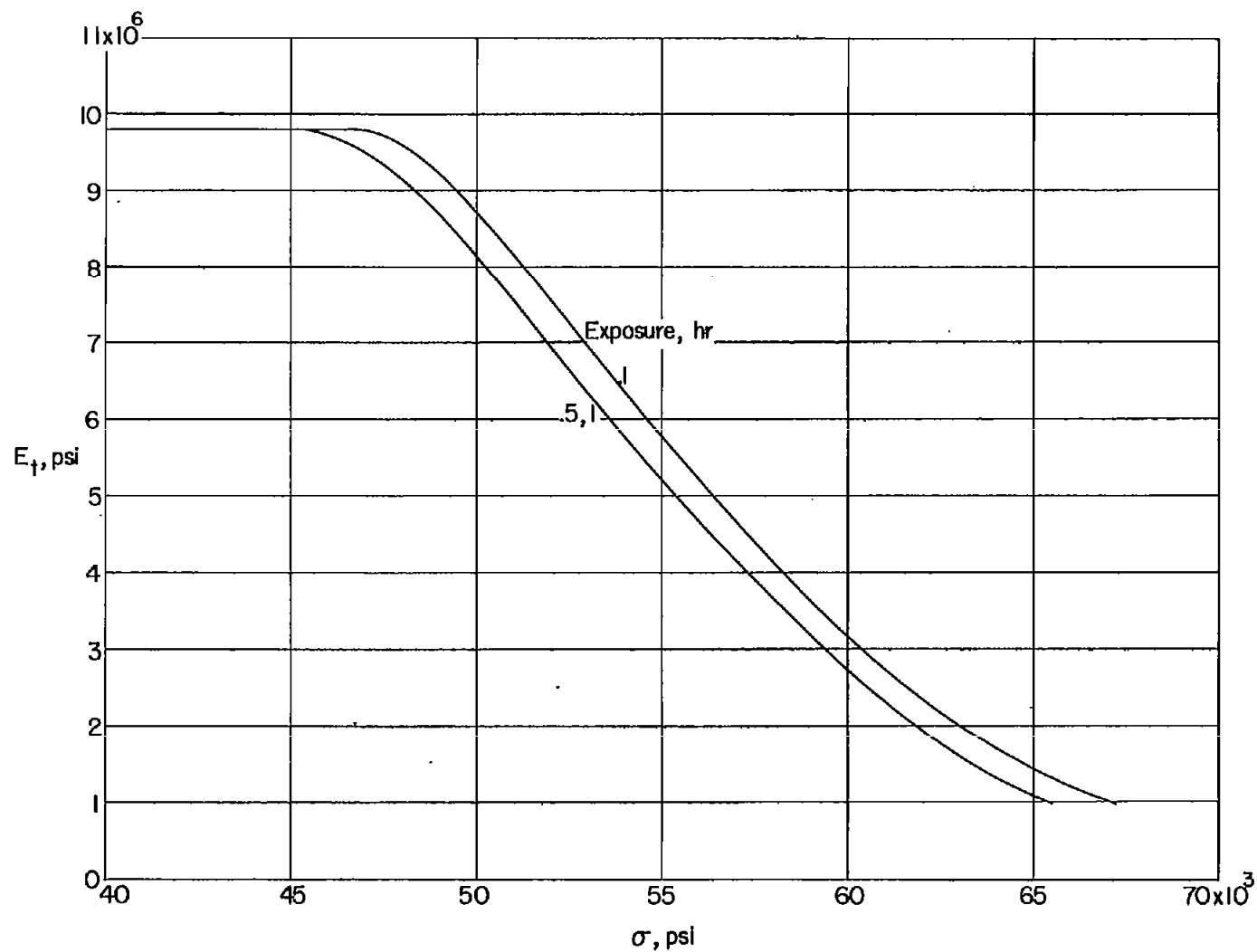
Figure 20.- Variation of secant modulus with stress for 7075-T6 aluminum-alloy sheet at 250° F.
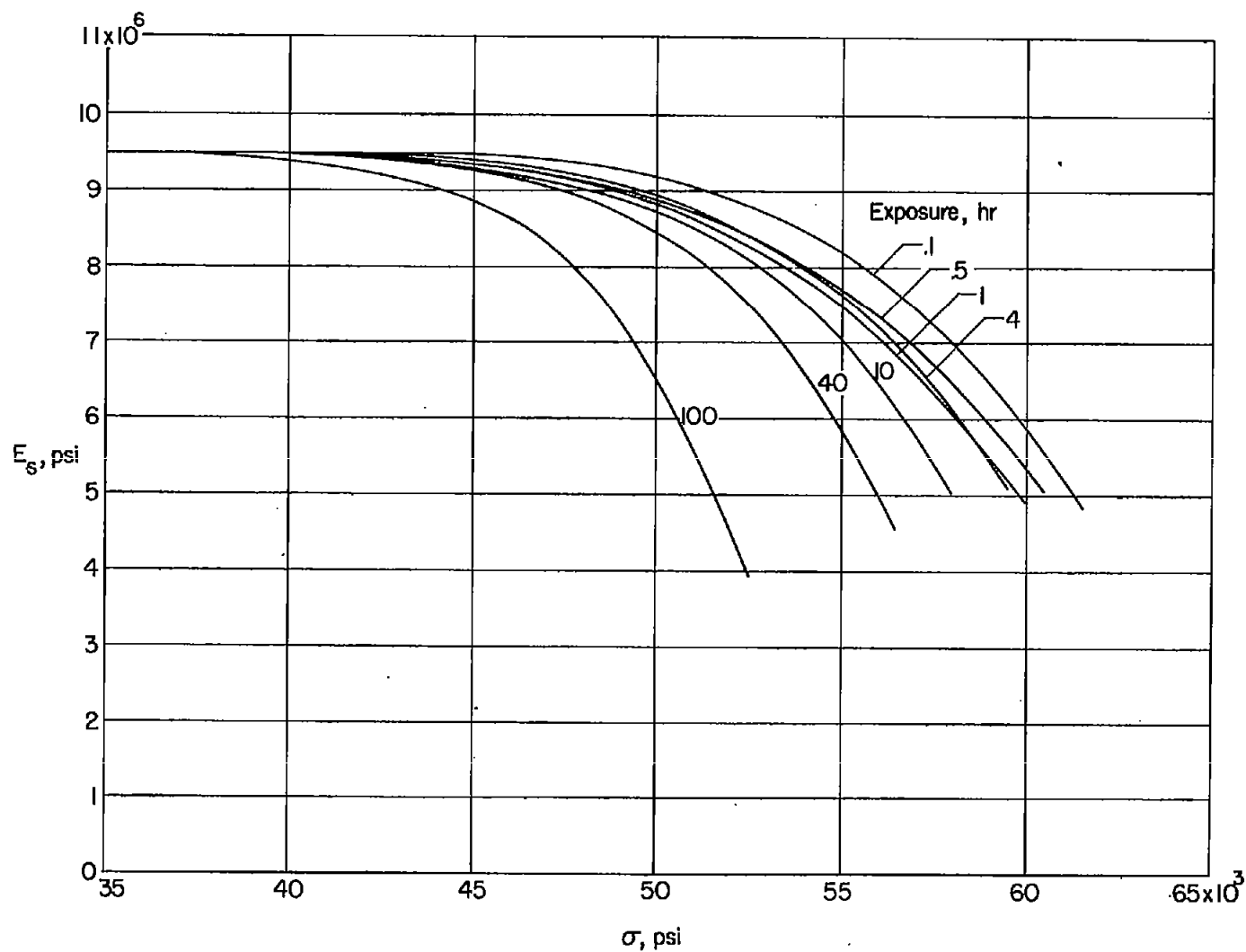
Figure 21.- Variation of secant modulus with stress for 7075-T6 aluminum-alloy sheet at 300° F.
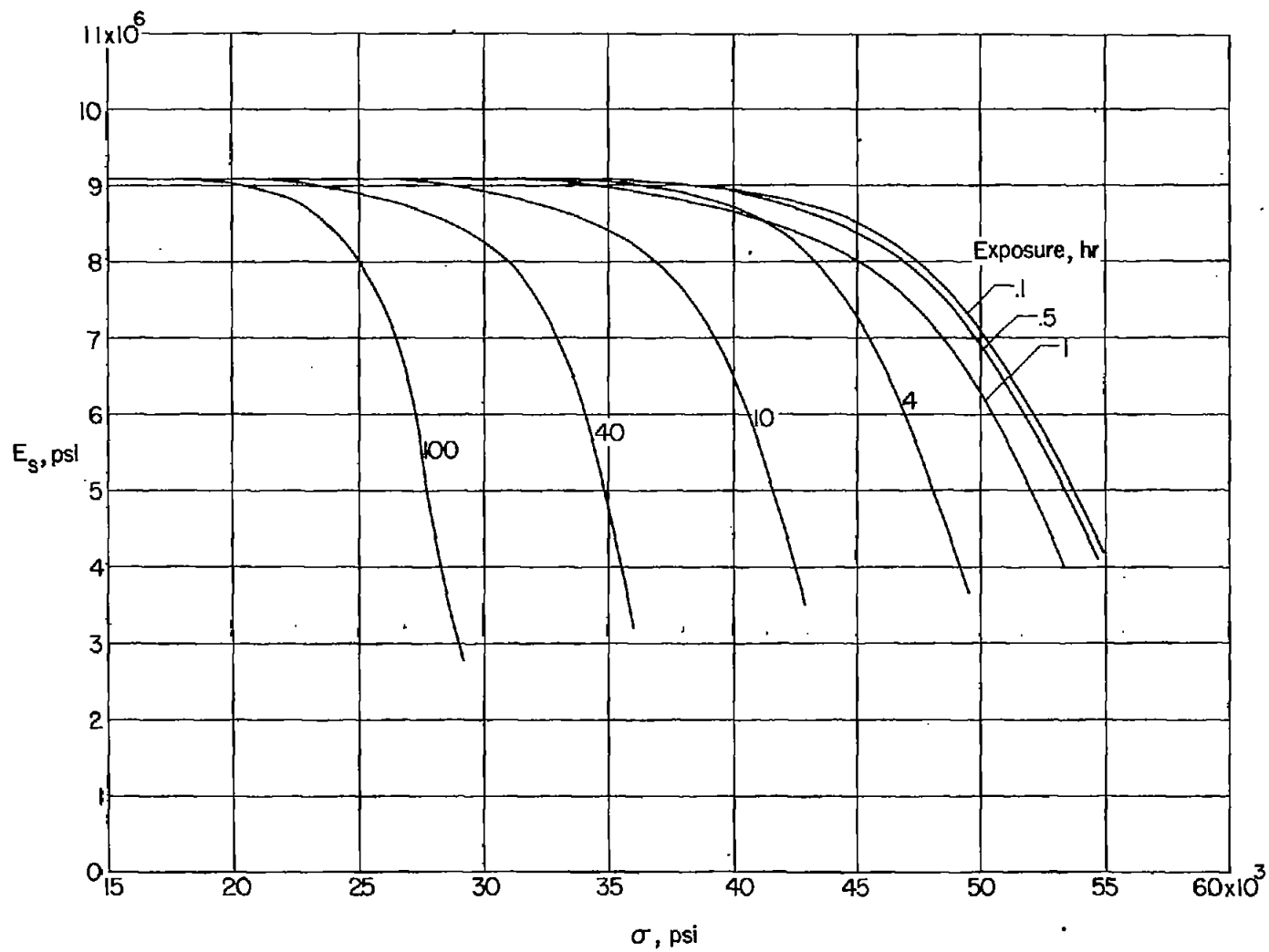
Figure 22.- Variation of secant modulus with stress for 7075-T6 aluminum-alloy sheet at 350° F.
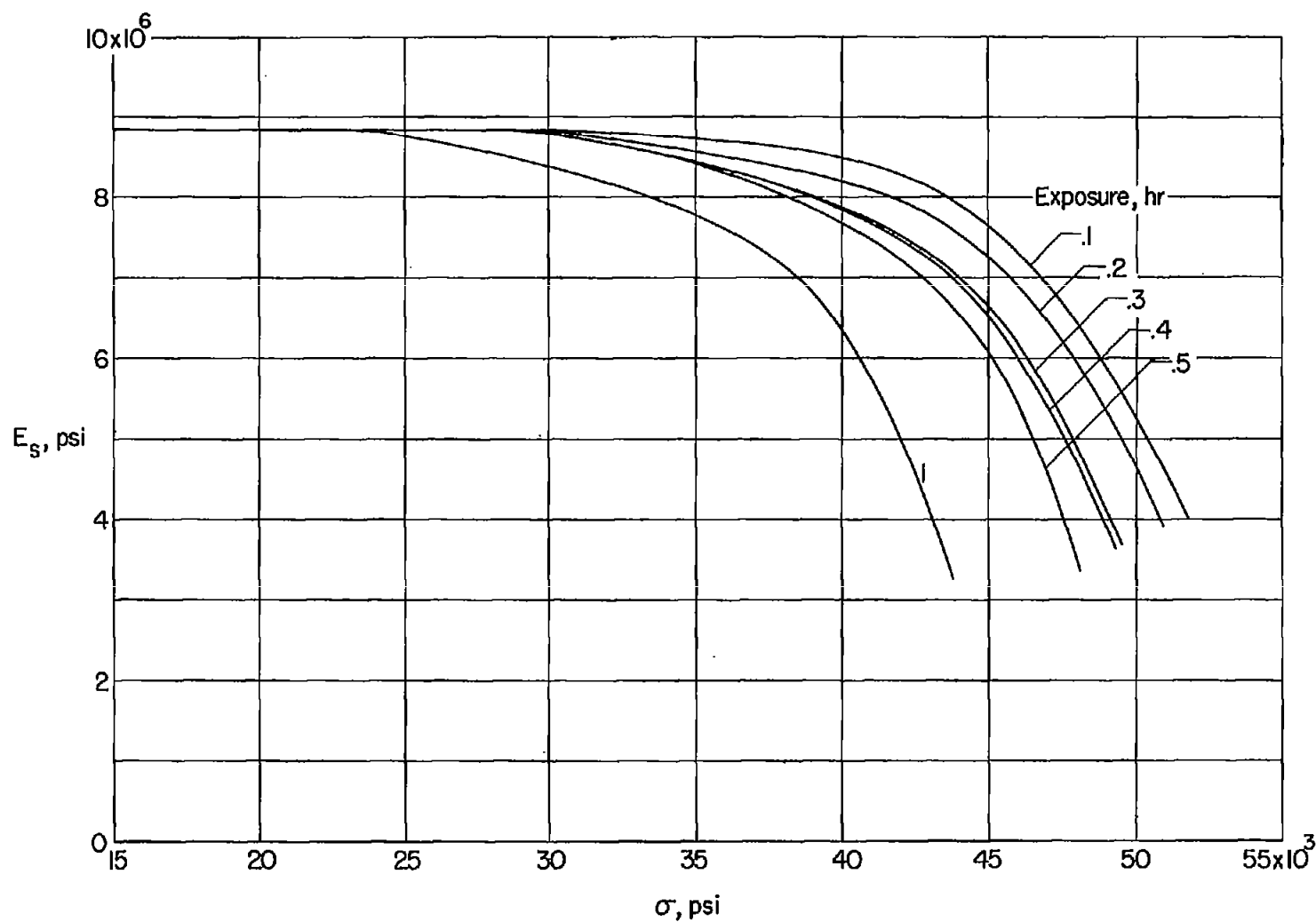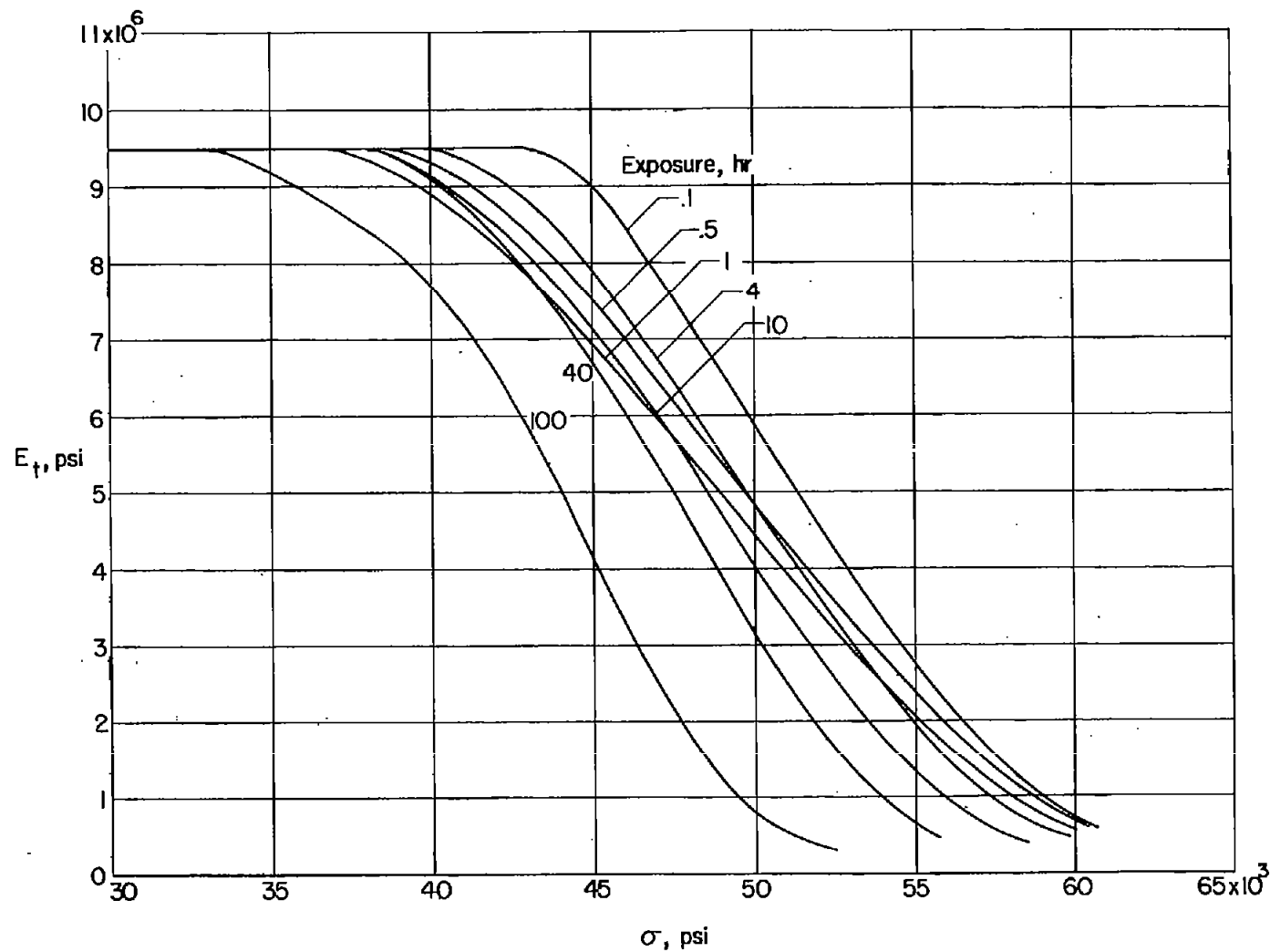
Figure 23.- Variation of secant modulus with stress for 7075-T6 aluminum-alloy sheet at 375° F.
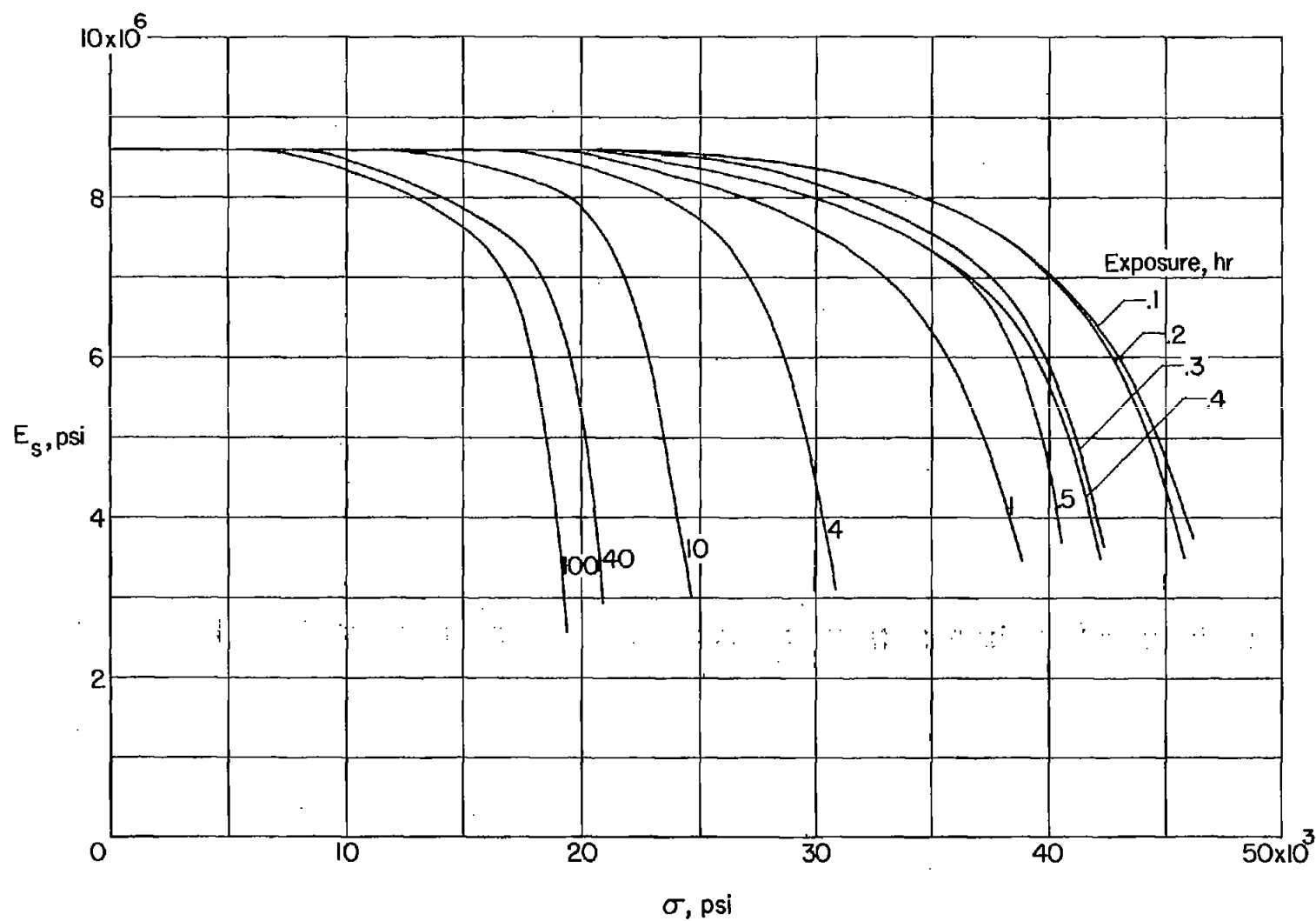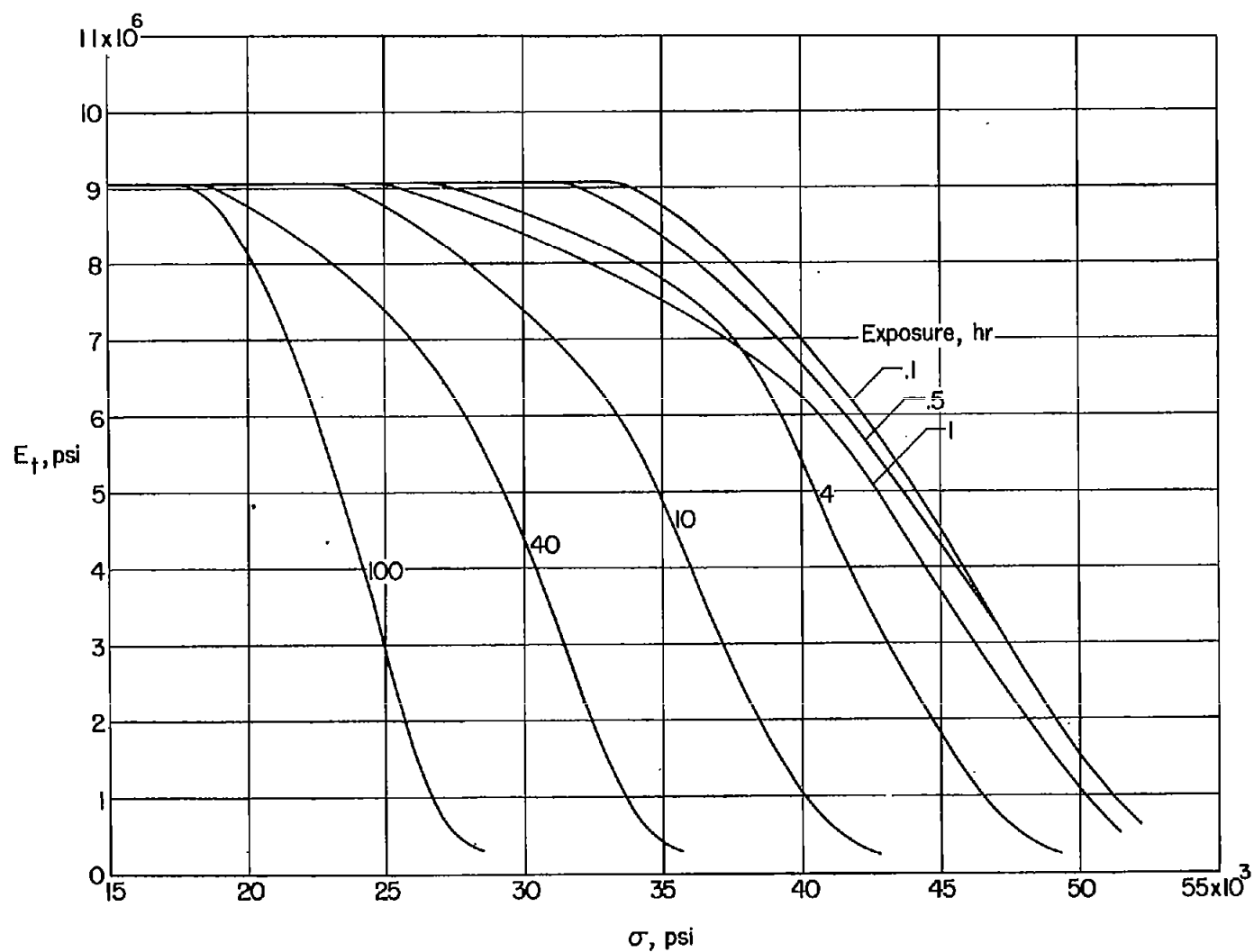
Figure 24.- Variation of secant modulus with stress for 7075-T6 aluminum-alloy sheet at 400° F.
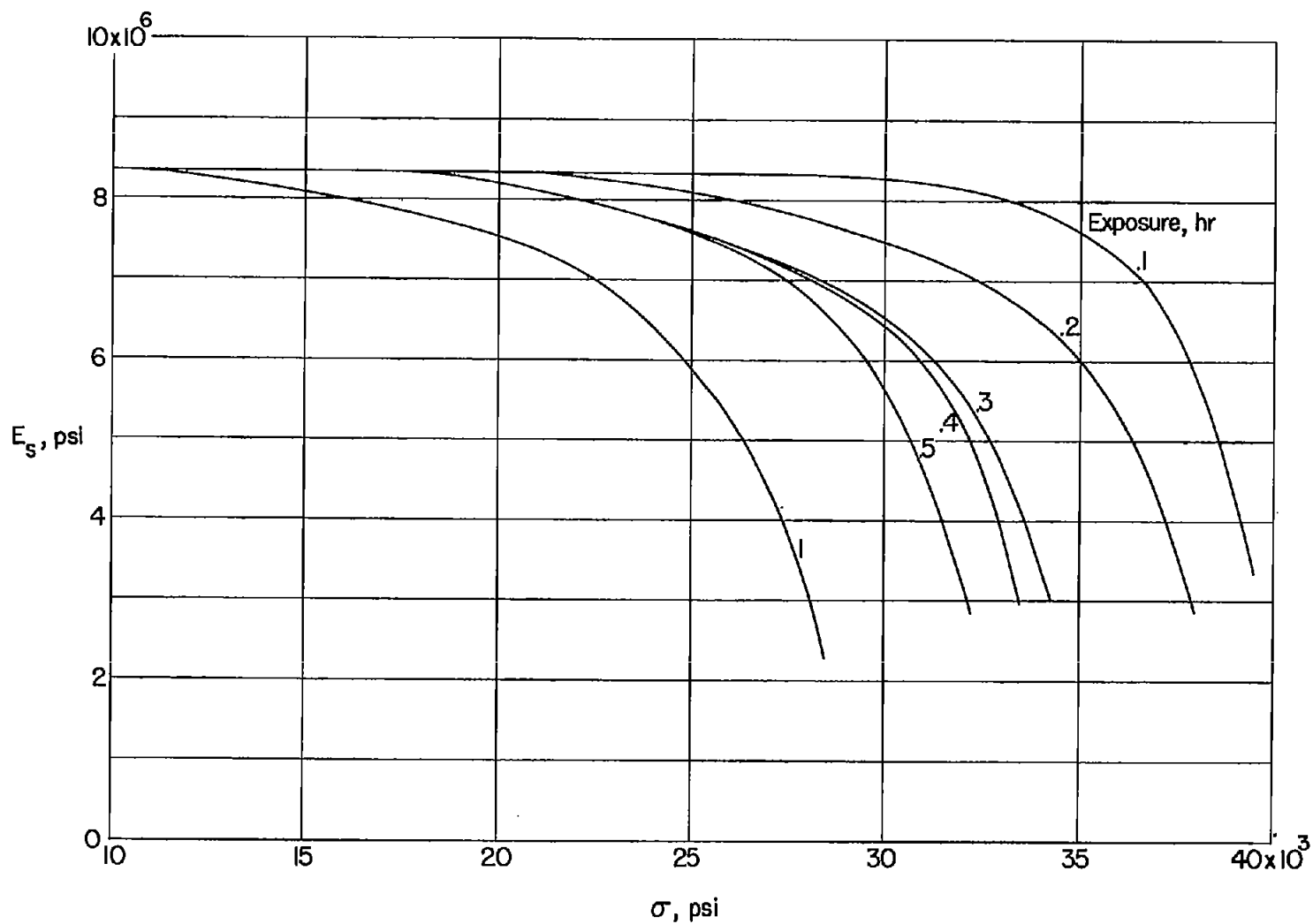
Figure 25.- Variation of secant modulus with stress for 7075-T6 aluminum-alloy sheet at 425° F.
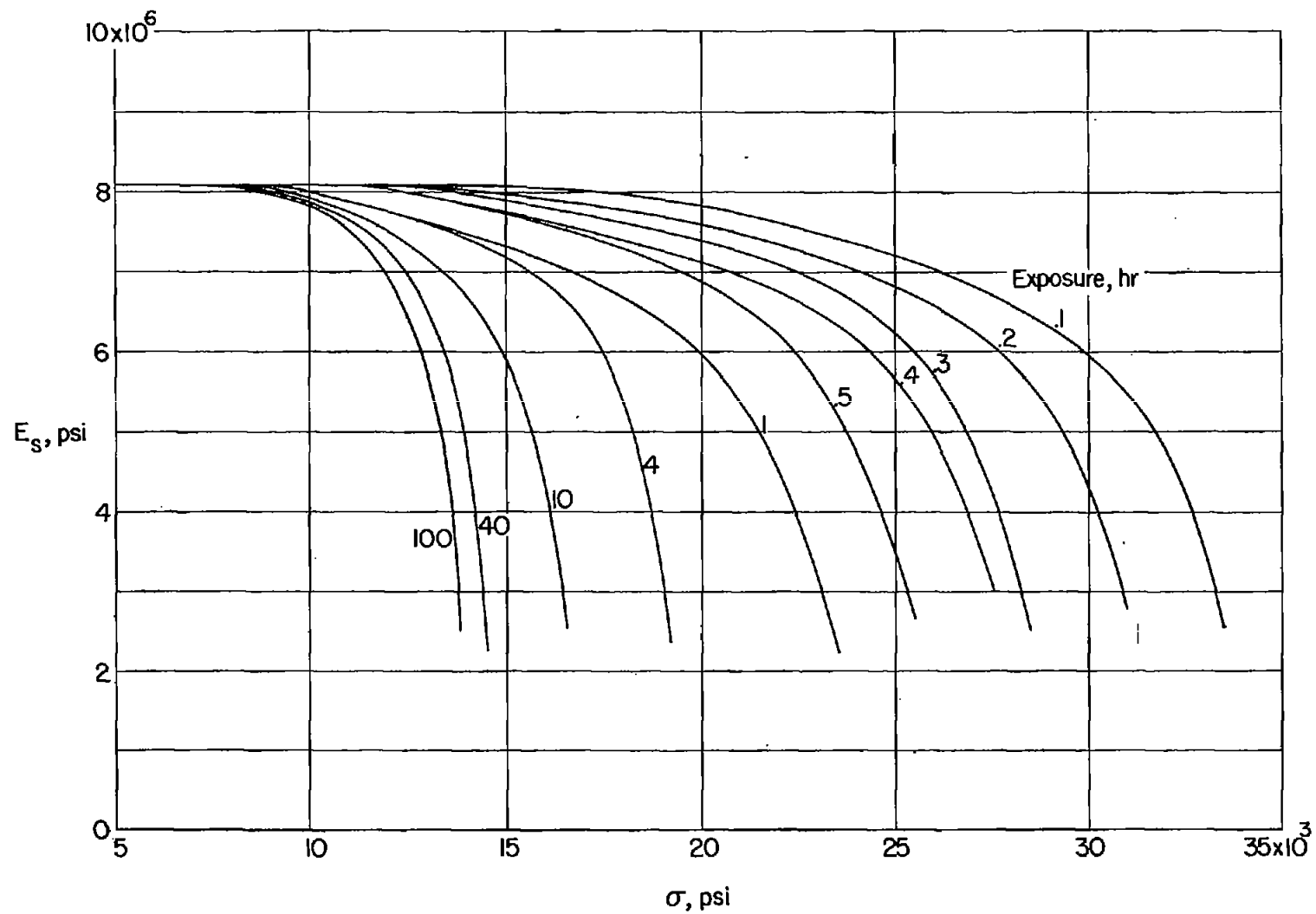
Figure 26.- Variation of secant modulus with stress for 7075-T6 aluminum-alloy sheet at 450° F.
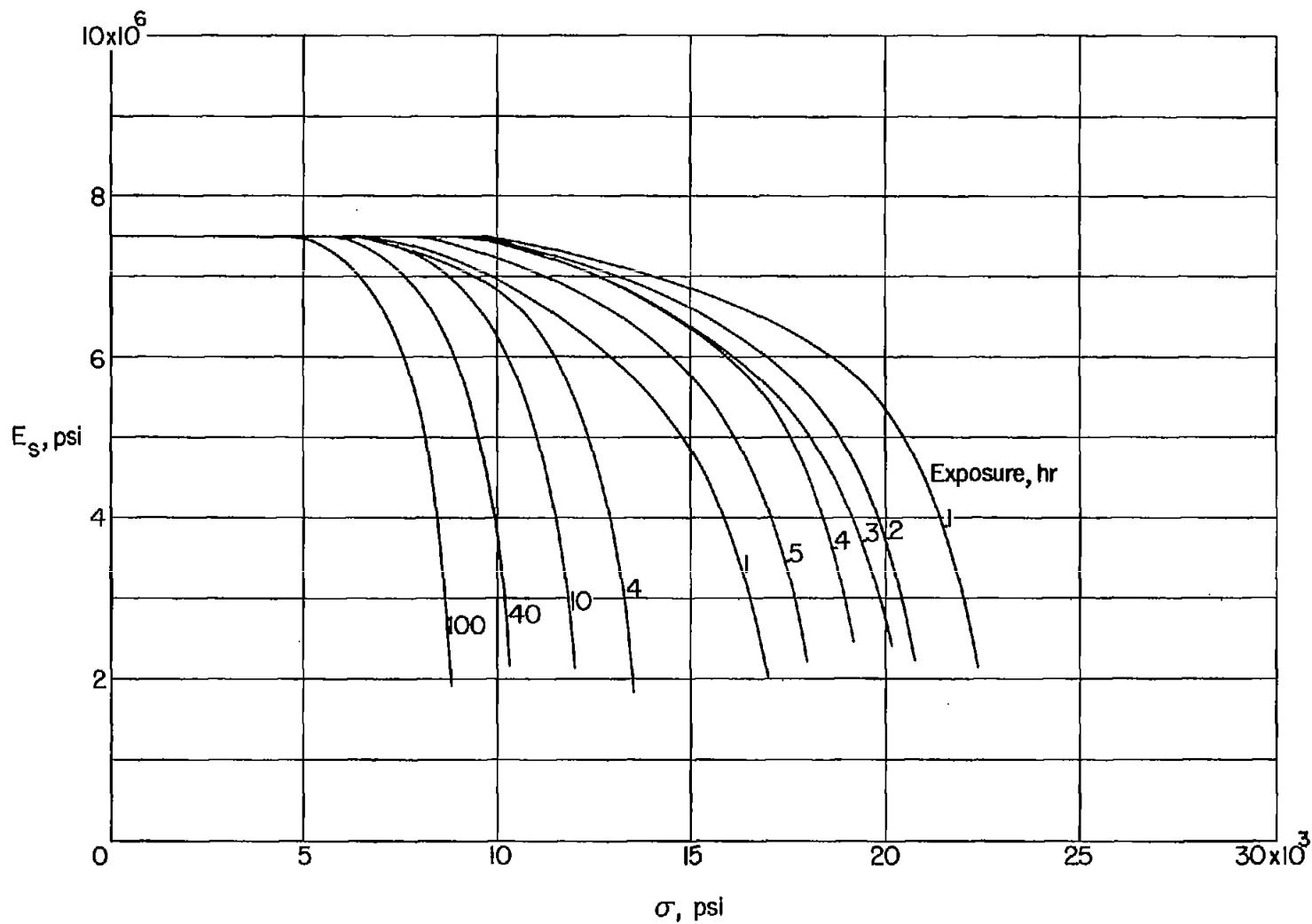
Figure 27.- Variation of secant modulus with stress for 7075-T6 aluminum-
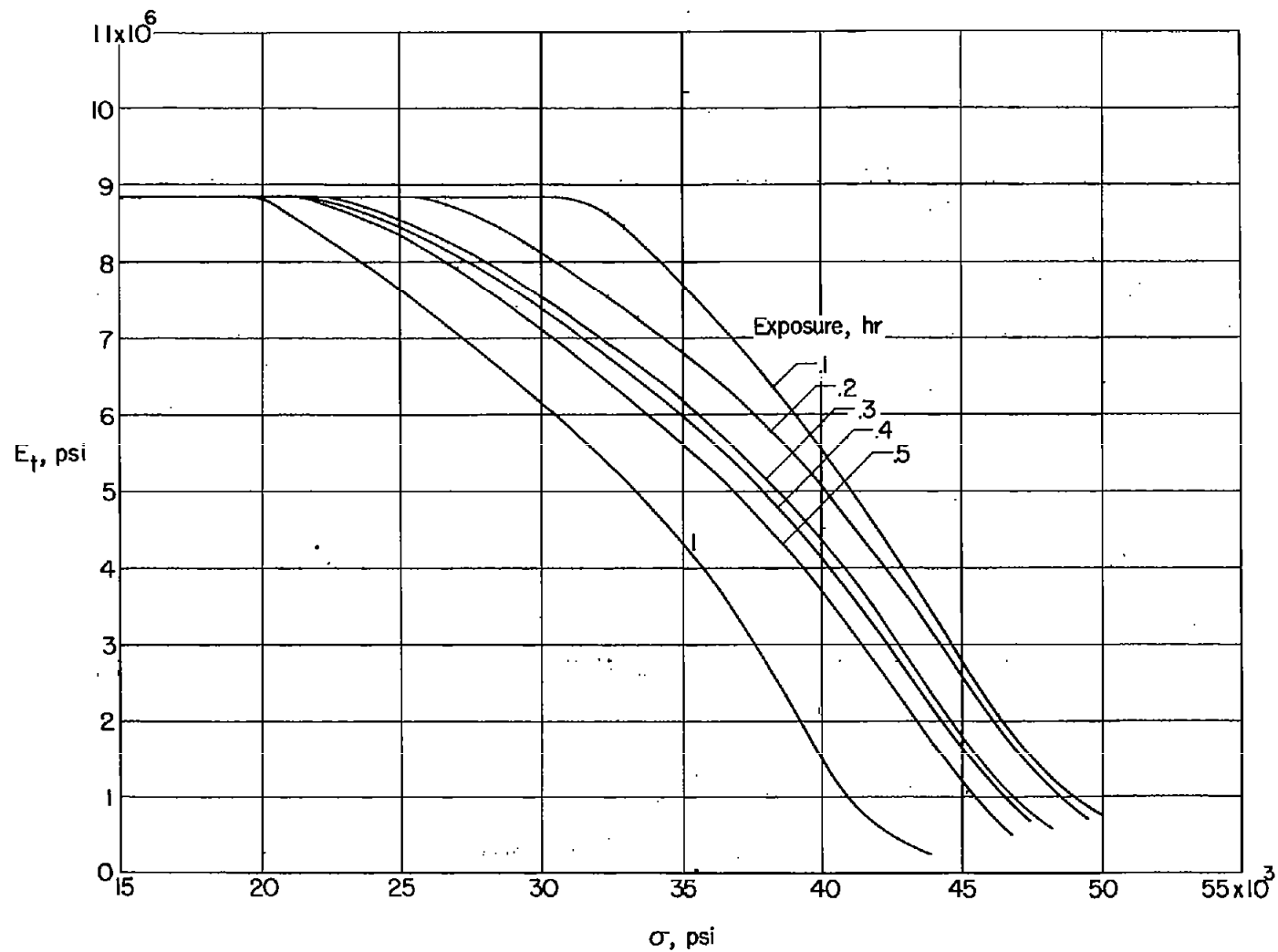alloy sheet at 500° F.
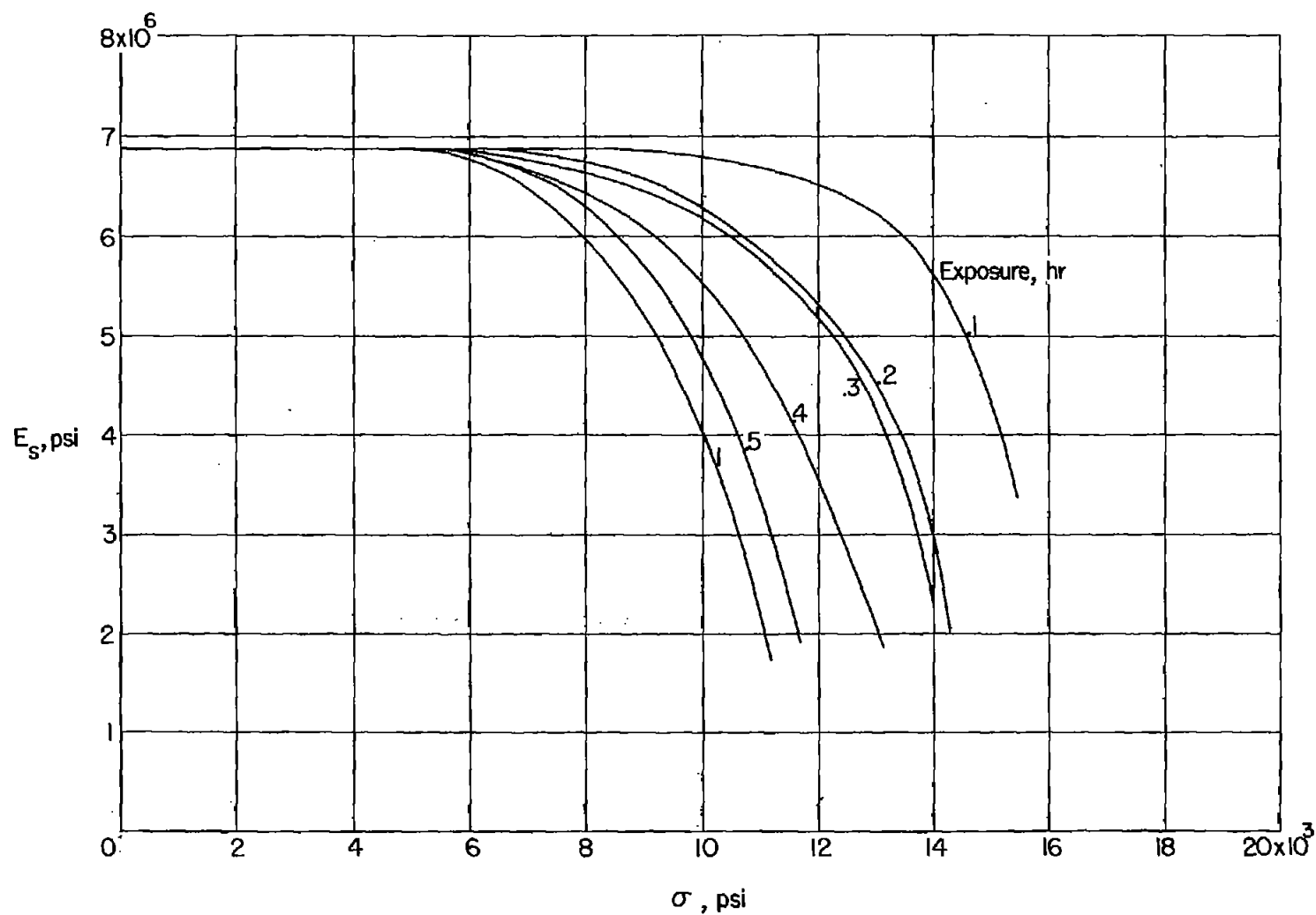
Figure 28.- Variation of secant modulus with stress for 7075-T6 aluminum-
alloy sheet at 550° F.
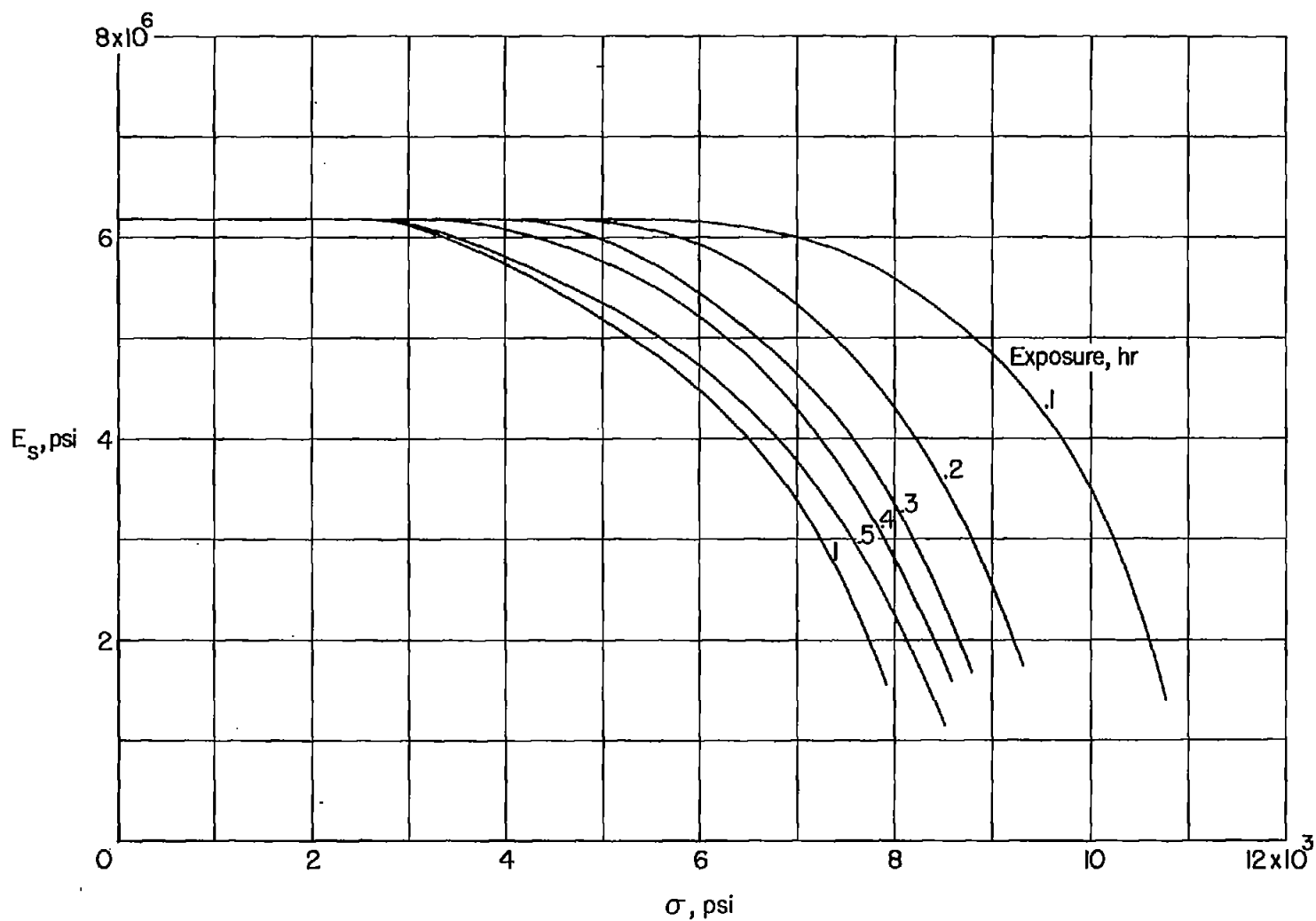
Figure 29.- Variation of secant modulus with stress for 7075-T6 aluminum-alloy sheet at 600° F.
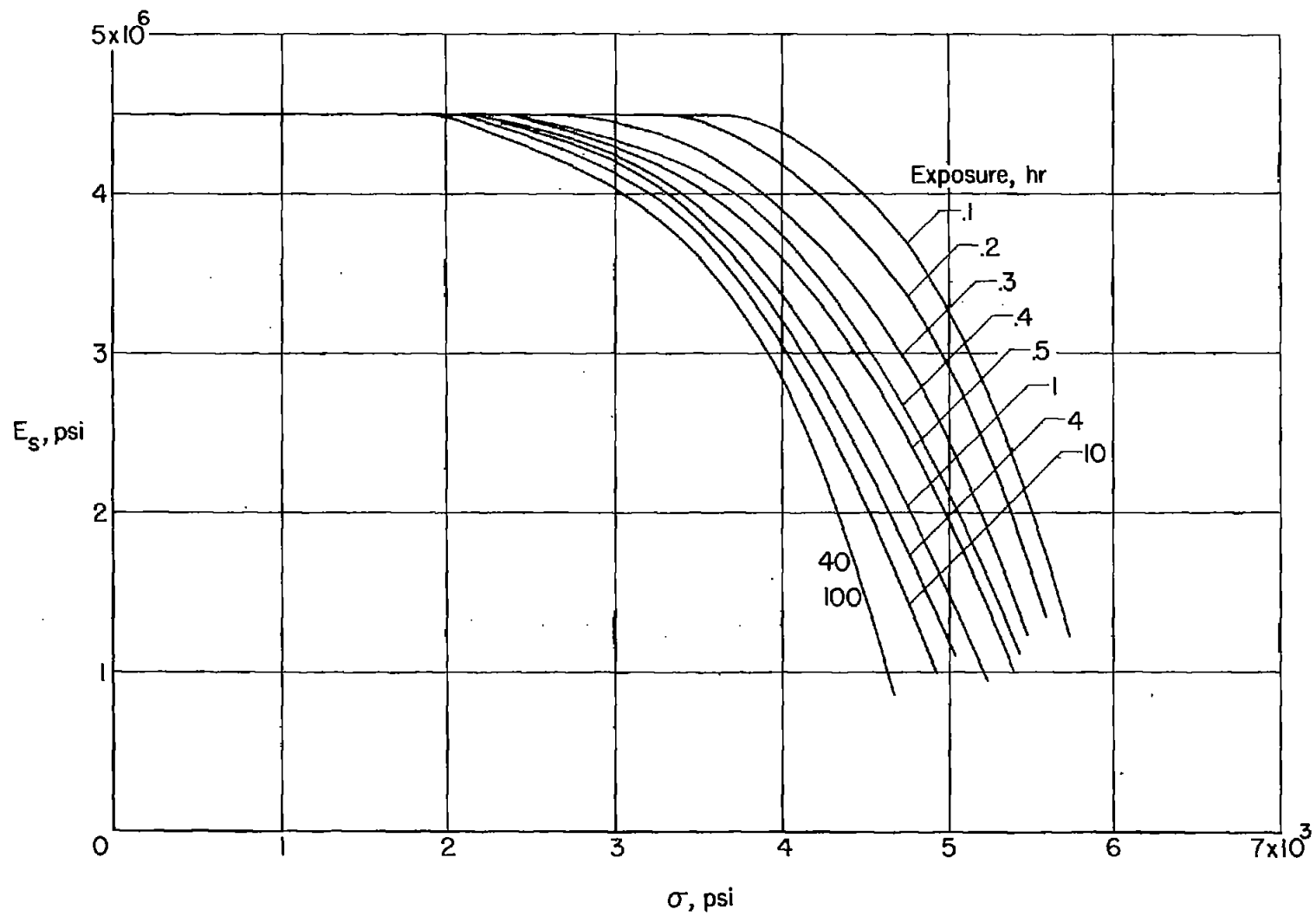
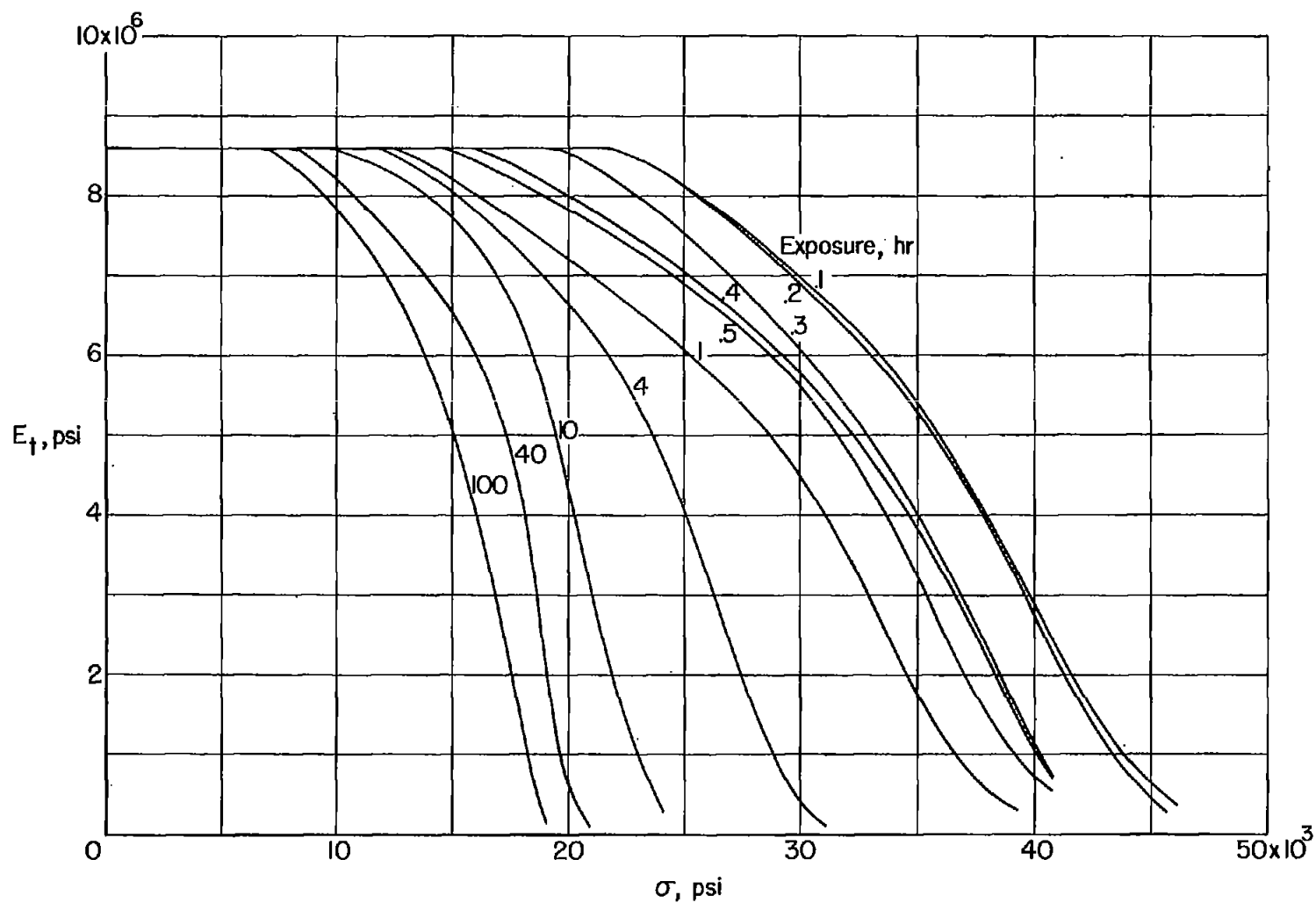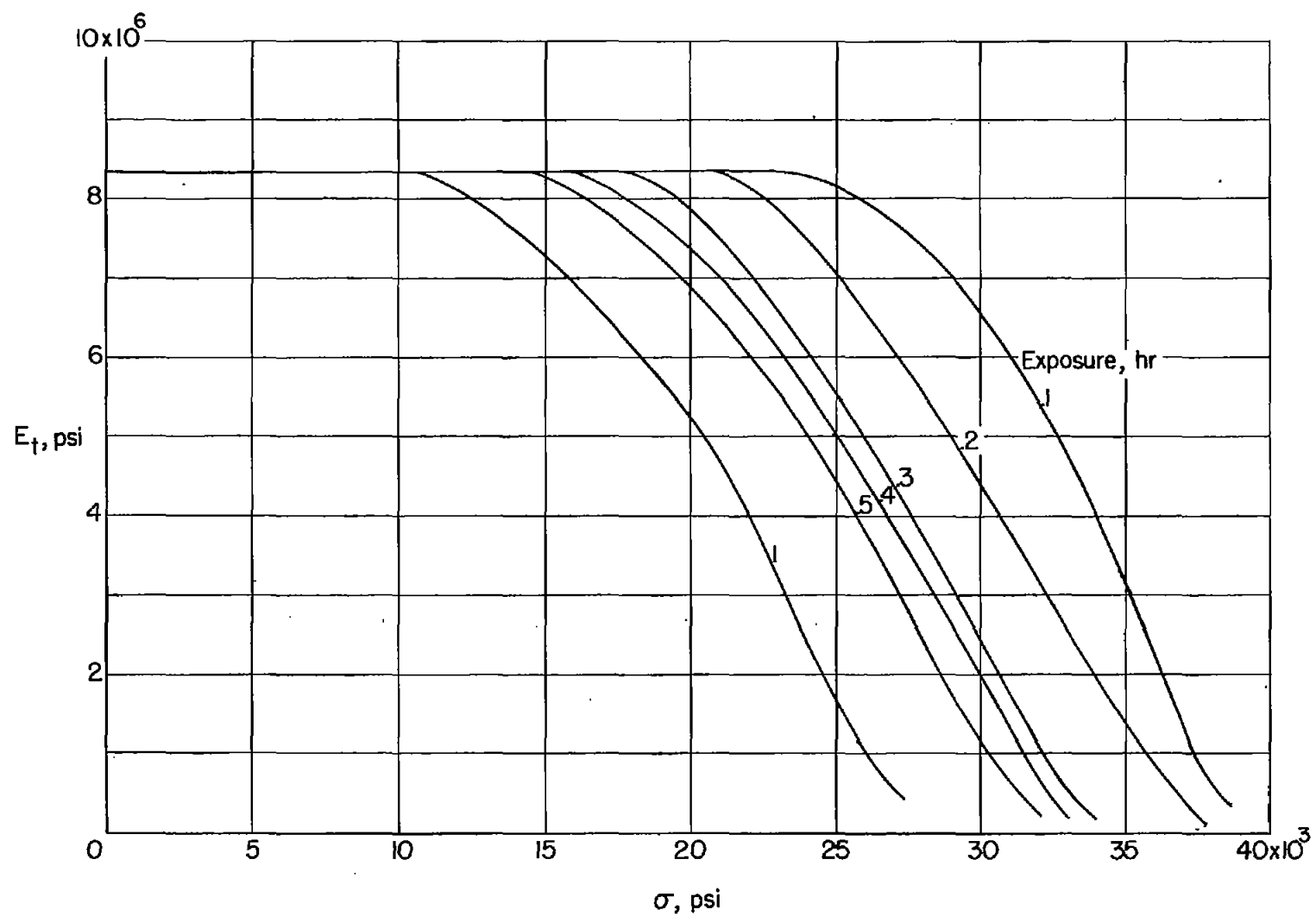Figure 30.- Variation of secant modulus with stress for 7075-T6 aluminum-alloy sheet at 700° F.

Figure 31.- Variation of tangent modulus with stress for 7075-T6 aluminum-alloy sheet. 0.5-hour exposure.

Figure 32.- Variation of tangent modulus with stress for 7075-T6 aluminum-alloy sheet at 200° F.

Figure 33.- Variation of tangent modulus with stress for 7075-T6 aluminum-alloy sheet at 250° F.
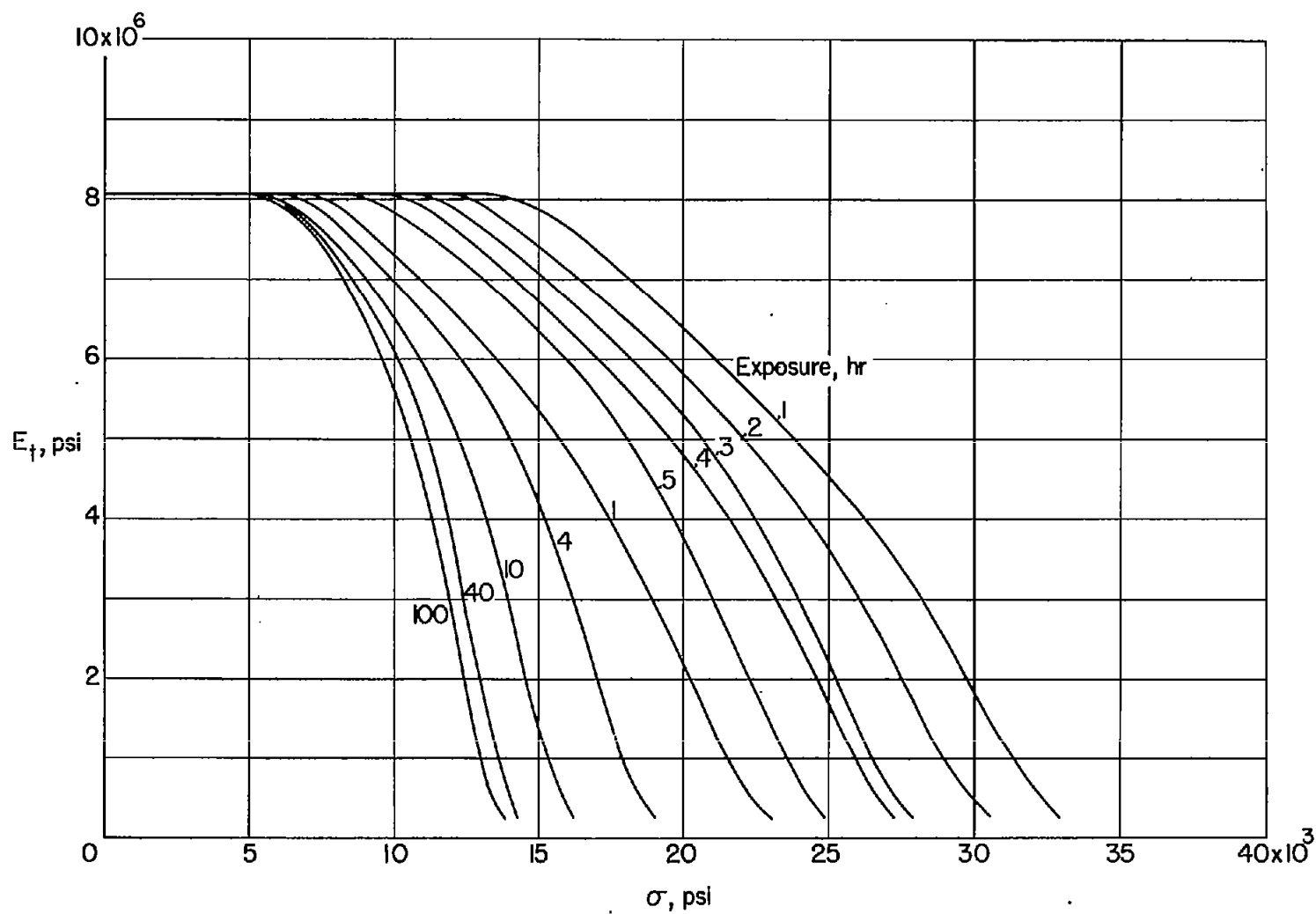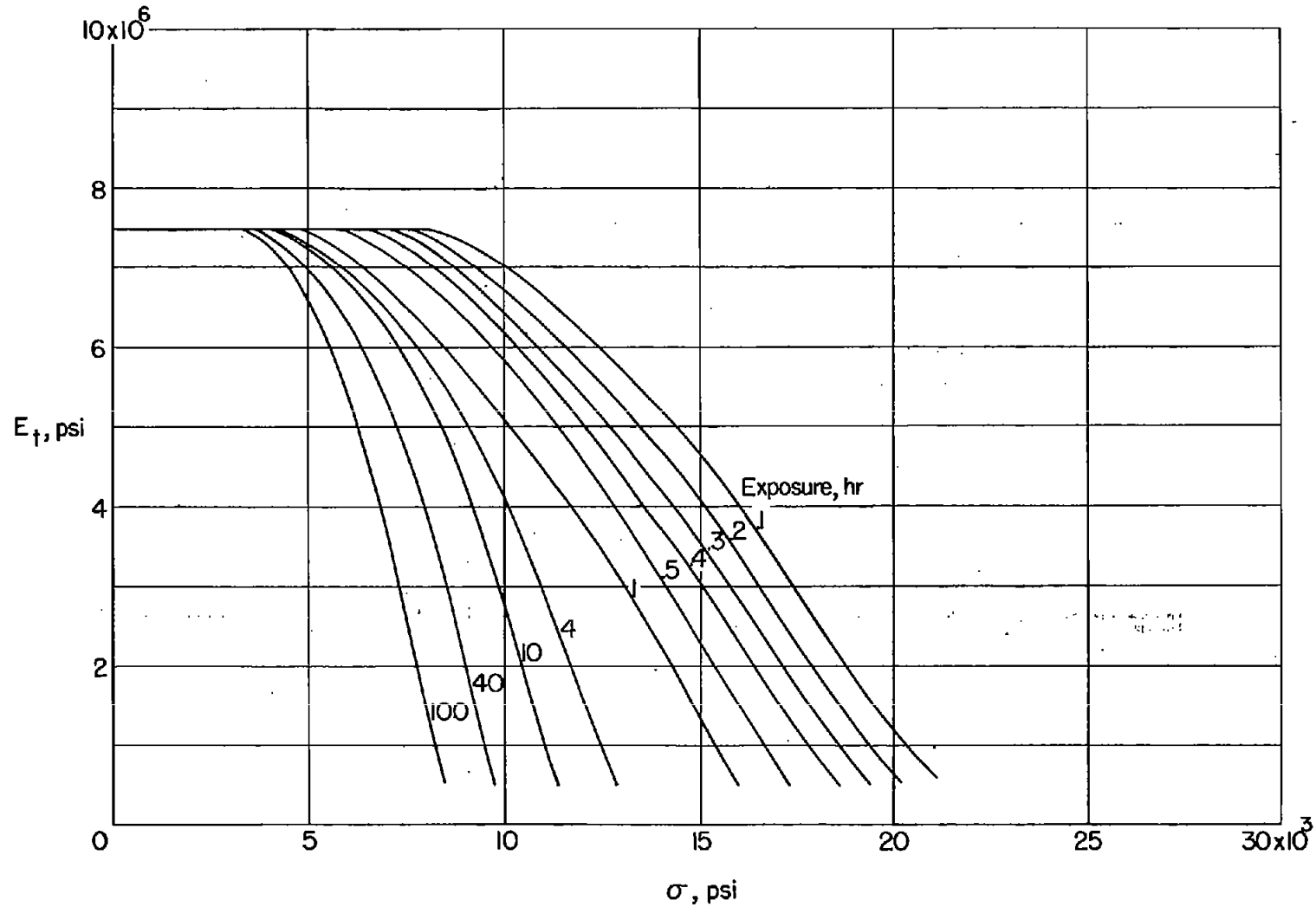
Figure 34.- Variation of tangent modulus with stress for 7075-T6 aluminum-alloy sheet at 300° F.
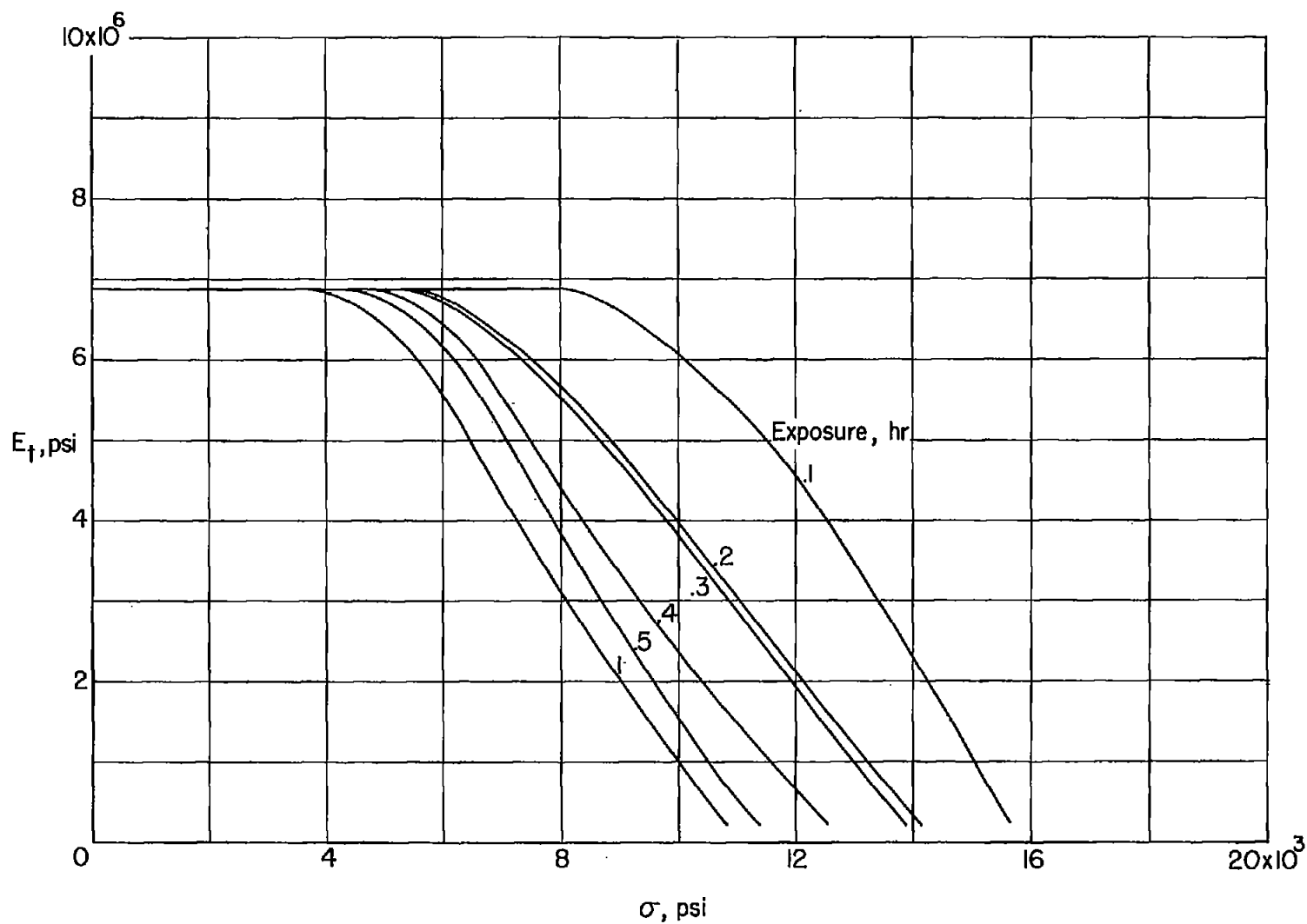
Figure 35.- Variation of tangent modulus with stress for 7075-T6 aluminum-alloy sheet at 350° F.

Figure 36.- Variation of tangent modulus with stress for 7075-T6 aluminum-alloy sheet at 375° F.

Figure 37.- Variation of tangent modulus with stress for 7075-T6 aluminum-alloy sheet at 400° F.

Figure 38.- Variation of tangent modulus with stress for 7075-T6 aluminum-
alloy sheet at 425° F.

Figure 39.- Variation of tangent modulus with stress for 7075-T6 aluminum-
alloy sheet at 450° F.

Figure 40.- Variation of tangent modulus with stress for 7075-T6 aluminum-alloy sheet at 500° F.

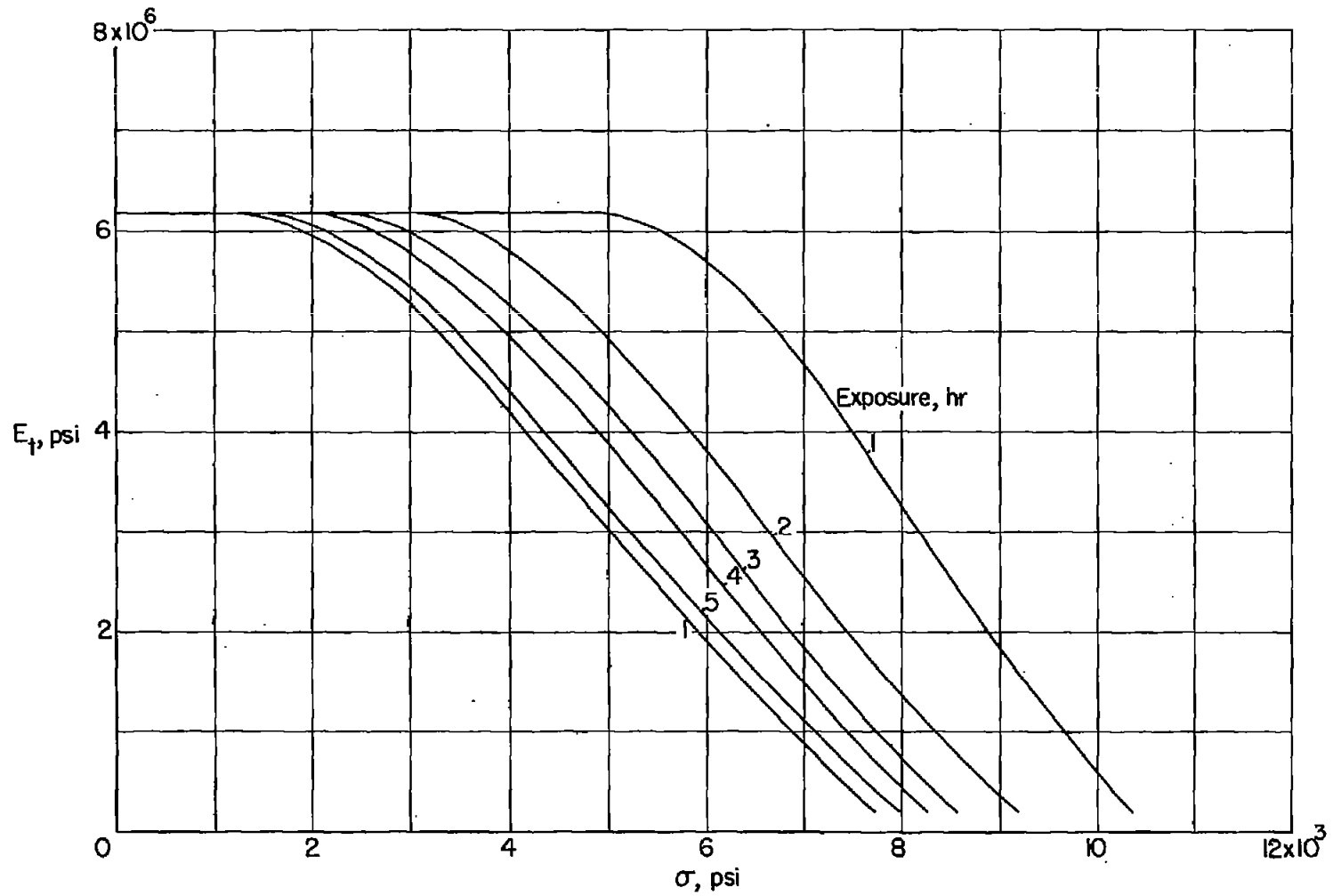Figure 41.- Variation of tangent modulus with stress for 7075-T6 aluminum-alloy sheet at 550° F.

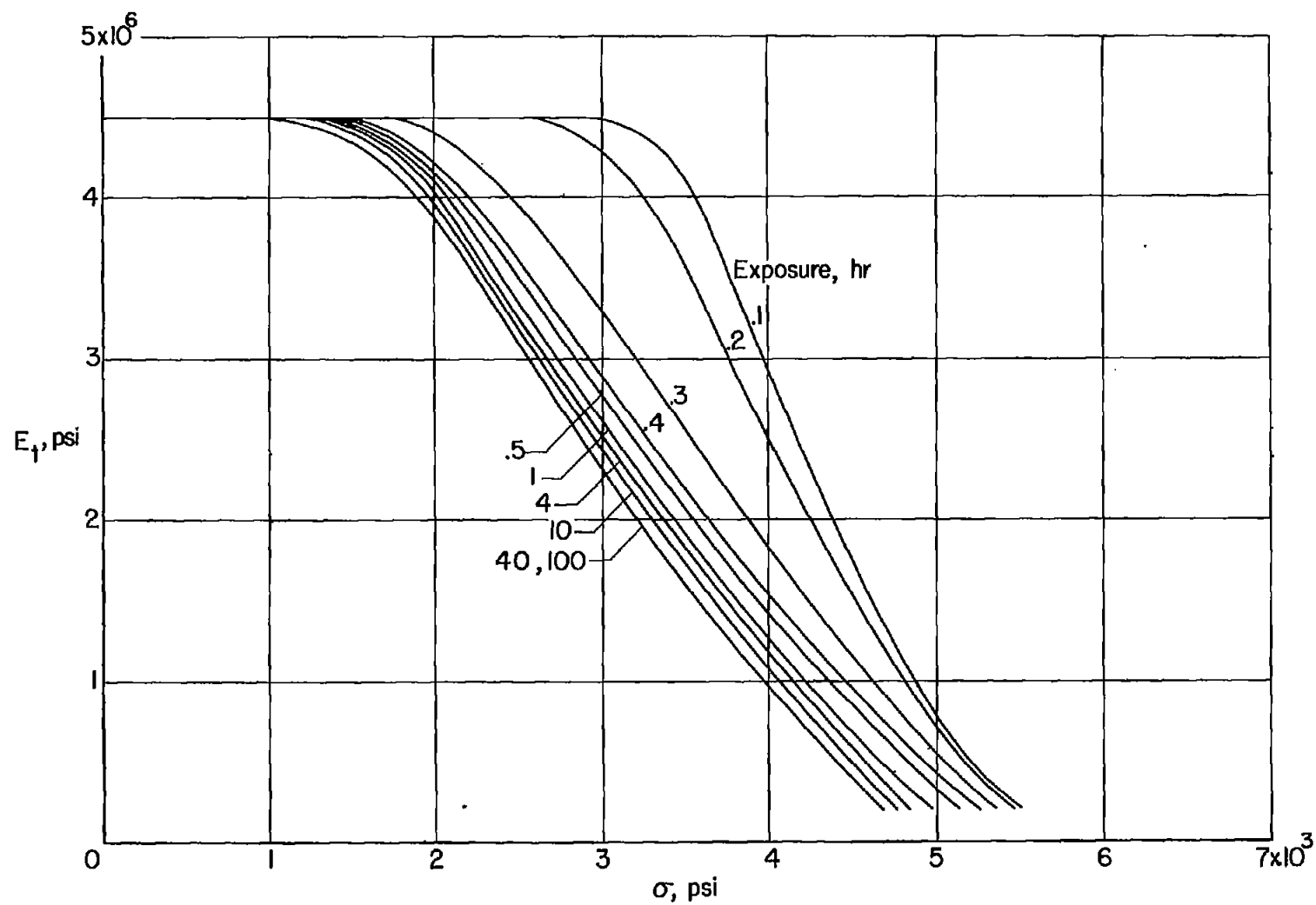Figure 42.- Variation of tangent modulus with stress for 7075-T6 aluminum-alloy sheet at 600° F.

Figure 43.- Variation of tangent modulus with stress for 7075-T6 aluminum-alloy sheet at 700° F.
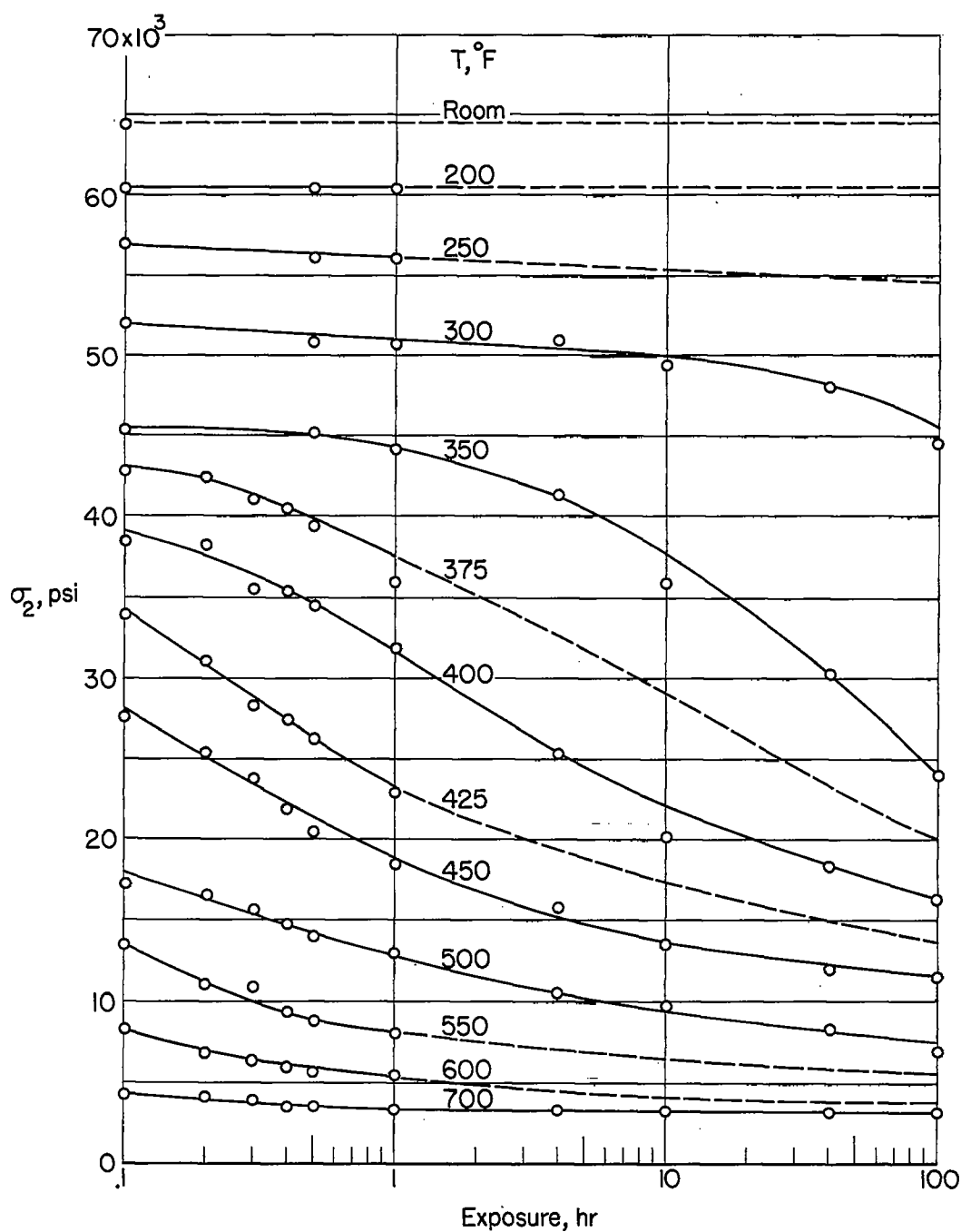
Figure 44.- Effect of temperature and exposure time on σ_2 for 7075-T6 aluminum-alloy sheet. (Dashed portions of curves indicate estimated results obtained from cross plots as in fig. 17.)
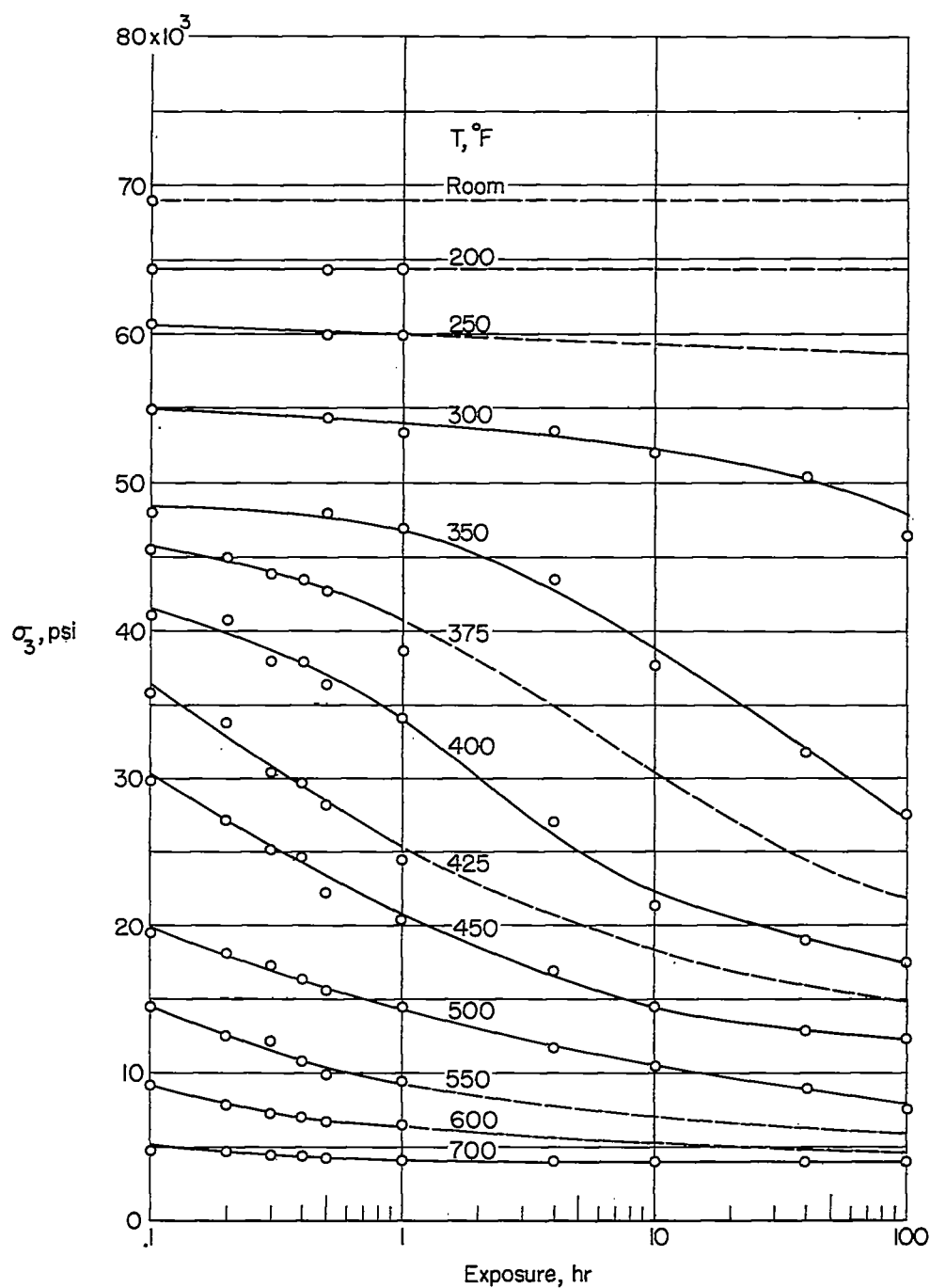
Figure 45.- Effect of temperature and exposure time on σ_3 for 7075-T6 aluminum-alloy sheet. (Dashed portions of curves indicate estimated results obtained from cross plots as in fig. 17.)
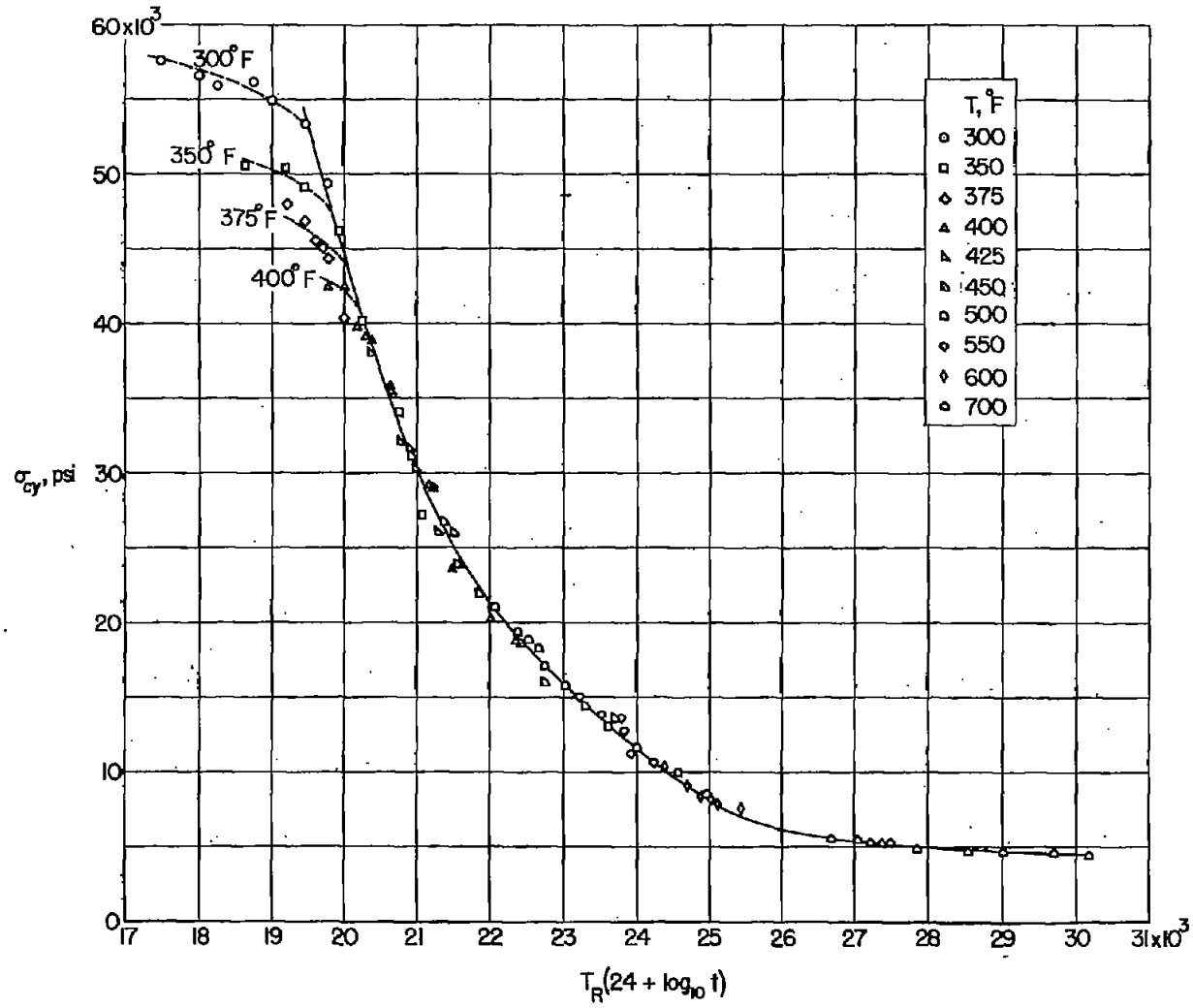
Figure 46.- Master curve of 0.2-percent-offset compressive yield stress
for 7075-T6 aluminum-alloy sheet.